CASE STUDY 4

COMPARISON OF THE EU AND US APPROACHES TOWARDS CONTROL OF PARTICULATE MATTER

4 October 2004

1. INTRODUCTORY OVERVIEW

Particulate air pollution is a mixture of solid, liquid and combined solid and liquid particles suspended in the air. These suspended particles vary in size, composition and origin. These particles can be emitted directly into the atmosphere (primary particles) or formed in the atmosphere (secondary particles) from gaseous or particulate pollutants. Natural particles (e.g. soil dust) and gases (e.g. from vegetation) also play a role. A more detailed description of PM pollution is given in annex 1 "Particle characterisation and health effects of PM".

Exposure to particulate matter has been found to be associated with increases in hospital admissions for cardiovascular and respiratory disease and mortality in many cities in Europe, in the US and other continents (WHO, 2001 and Pope *et al*., 2002). These particles are also carriers of acidifying and eutrophying substances. In addition, in virtually all areas of the US, there have been growing concerns about deteriorating visibility and especially in national parks and wilderness areas, though this is not considered a serious problem in Europe at present.

2. COMPARISON OF THE TWO APPROACHES

To understand the effectiveness of the legislation to address particulate matter in the EU-15 and the US, it is useful to compare the results of the two approaches. To a large extent, past legislation and regulations in both countries have been aimed at PM_{10}. As a result, assessing the effectiveness of PM10 efforts is more appropriate. However, $PM_{2.5}$ has become an increasing area of focus and it is therefore useful to consider trends in this category of PM as well. Greater details on the legislation adopted and regulation implemented in the EU-15 and US is discussed in Annex II and III, respectively, to this section.

2.1. Particulate Matter in the EU

EU-level efforts to reduce PM pollution in Europe began with standards for black smoke or soot and have focused more recently on PM_{10}. The concern about health effects of PM pollution in Europe came on the political agenda in connection with the London Smoke episode in 1952 (coal), which led to development of legislation on emissions from combustion sources, especially in UK, with a focus on black smoke (BS or soot). Due to severe particle pollution in the most industrialised areas during the 1970s and 1980s it became necessary - both in relation to health concerns and dust nuisance - to include other parameters of the particles, e.g. the mass (suspended particulate matter, TSP) and later size (PM_{10}).

The first EU Directive 80/779/EEC on air quality limit values and guide values for sulphur dioxide and suspended particulates set limit values for PM in terms of TSP or BS. The setting of limit values and related control strategies changed to become more impact related during the 1990s, e.g. in connection with the Daughter Directives under the Air Quality Framework Directive 96/62/EC, which in relation to health mainly was based on WHO's recommendations. The AQFD includes PM as fine particles, while the first Daughter Directive 99/30/EC on limit values for SO_2, NO_x, PM and lead gives the standard for particulates as PM_{10}. For details, see the database on standards.

The first Daughter Directive is now under review, and proposals for limit values on $PM_{2.5}$ are expected, with some standard maintained on coarse particles, i.e. $PM_{2.5\text{-}10}$. It has been recommended that the annual average limit value should be in the range 12 to 20 µg/m³, and that the 24-hour average limit value should be in the range (20 to 35 µg/m3, not to be exceeded more than 10% of the days of the year). The values are to be reconsidered in view of the results of an integrated assessment.

Control of emissions and secondary particles. The initial 1980 emissions standard for suspended particulates was followed up by emission legislation on different ***industrial sources***, e.g. the Directive

88/609/EEC on the limitation of certain pollutants into the air from large combustion plants (LCP) and Directive 96/61/EC on integrated pollution prevention and control (IPPC), both setting limits on emissions of dust. More recently, Directive 2001/80/EC aims to limit emissions from large combustion plants even further. Especially the IPPC directive to assist the Member States in assessing BAT, including possibilities of using electrostatic precipitators and tissue filters, scrubbers, cyclones etc.

Secondary particles formed from precursors contribute to approximately 86% of total PM_{10} emission in the EU-15. The CLRTAP and the NEC Directive cover the main precursors of secondary particles.

Control of mobile sources (especially road traffic) is based on emission limits for vehicles and fuel quality standards. The first EU-level control was Directive 70/220/EEC on emissions from motor vehicles. This was followed up by a number of Directives on emissions from different types of vehicles and fuel quality, e.g. reduction of sulphur content in diesel fuel. The so-called EURO standards include emission limits of PM given as mass per km or per kWh. The EURO standards are comparable with those in the US (see *Figure 1* for diesel vehicles). Similar standards exist for petrol vehicles.[1] See also the database on standards.

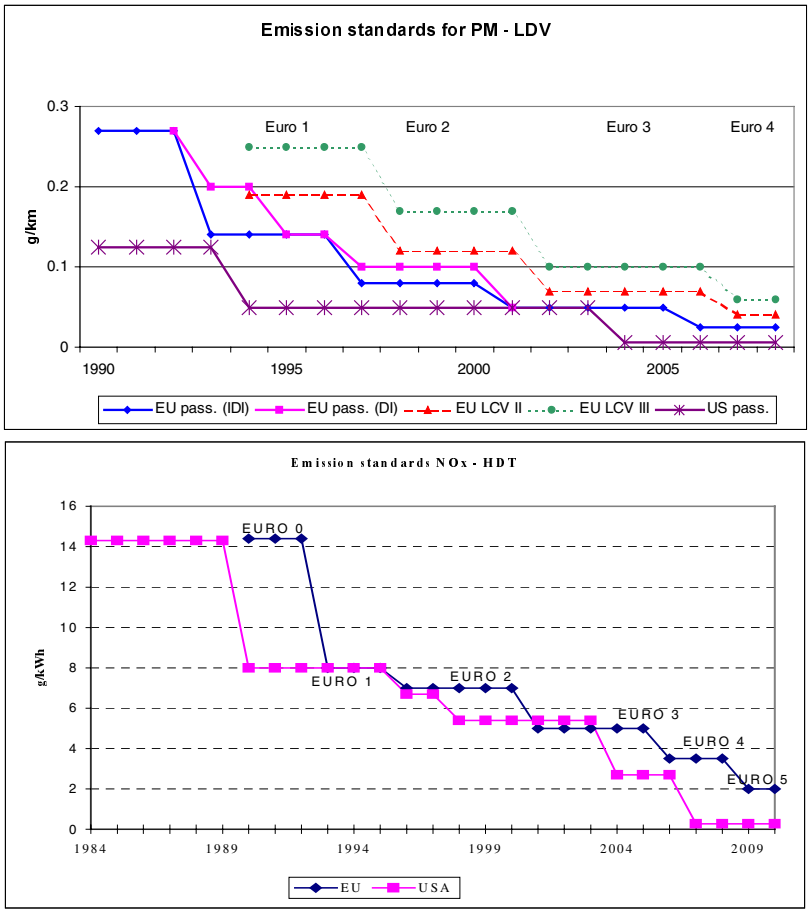


Figure 1 Emission standards for diesel vehicles in the EU and the US, g/km for LDV and g/kWh for HDV.

Emission standards in EU for light duty diesel vehicles cover: IDI refers to Indirect Injection, DI to direct. In the EU, there are 3 classes of Light Commercial Vehicles (LCV): I weight < 1305 kg (same limits as passenger cars), II: weight 1305-1760 kg and III: weight > 1760 kg. California has had lower standards than national, but they are currently at the same level as the national standards.

[1] A complete list of EU directives is given in: http://europa.eu.int/comm/enterprise/automotive/directives/vehicles/index.htm.

Emission standards for mobile sources are also under review as of 2004. The EURO V and Euro VI are under discussion. The EURO V standards are related to passenger cars & light commercial vehicles and include – reduction in tailpipe emission limits of NO_x and reduction in diesel PM (mass and nano-PM.). The EURO VI standards are related to heavy-duty vehicles and reductions in NO_x in PM (mass and nano-PM). There is a strong pressure from some countries, e.g. Germany, to implement the EURO V standards already in 2007, instead of 2010 as planned, and also to strengthen the emission limits. The pressure is based on the requirements in the NEC directive and new findings on the health effects of particles. A new proposal is expected in 2005. At the moment it is not finally decided whether and when the EURO VI standards will be implemented, but a new proposal is expected in 2008.

There is limited control for some PM sources/emissions. Several sources of particles and precursors to particles are not controlled, or have only limited or national controls. They include: shipping, domestic heating (solid fuel), aviation, off-road machinery, farming, forestry, and constructions.

2.2. Particulate Matter in the US

Initial focus of control was on total suspended particles and PM_{10}. Early efforts to control PM focused on reducing large particles. As a result, early National Ambient Air Quality Standards (NAAQS) were established for total suspended particulate and later for PM_{10}. Control strategies in the past, therefore, have focused on reducing these particulates.

Recent focus has been given to $PM_{2.5}$. As a result of a review of the PM standards and scientific studies, EPA proposed revised PM standards in 1997. In addition to retaining the PM_{10} standards, EPA added a new annual $PM_{2.5}$ standard set at 15 $\mu g/m^3$ and a 24-hour standard set at 65 $\mu g/m^3$ to increase level of protection against the PM-related health effects. Since the promulgation of the $PM_{2.5}$ NAAQS, EPA has been developing implementation rules. So far, EPA issued guidance for state and local agencies on the area designation process in 2003. EPA also announced that it plans to make final area designations by December 2004, based on the air quality data from the years 2001-2003. In addition, EPA is currently reviewing both the PM_{10} and $PM_{2.5}$ standards as a part of their regular review and will produce a "criteria document" by the end of October 2004.

Regional haze control is a focus of planning and control efforts. In addition to the health-related issues, concerns about deteriorating visibility in virtually all areas of the US, especially national parks and wilderness areas, led to the inclusion in the CAA Amendments of 1977 a national goal to prevent and remedy visibility impairment due to anthropogenic pollution in Class I areas, which included most of the 156 national parks and wilderness areas. The 1990 CAA Amendments required EPA to establish regulations to ensure "reasonable progress" in improving visibility in Class I areas. In 1999, EPA promulgated the Regional Haze Rule in response to CAA visibility provisions. The rule has been the subject of lawsuits and was reissued earlier in 2004. States were required to develop long-term (10 to 15 years) implementation plans that include enforceable measures on all types of anthropogenic sources. In developing these plans, states were encouraged to work collaboratively with other states by forming regional planning organizations (RPOs), which led to the development of five such groups.

PM Emissions controls are in place for a variety of stationary sources. Emissions standards for PM are in place for a variety of stationary sources, including fossil-fuel fired generators, industrial-commercial-institutional steam generating units, small industrial-commercial-institutional steam generating units, incinerators, hospital/medical/infectious waste incinerators, Portland cement plants, hot mix asphalt facilities, petroleum refineries, secondary lead smelters, secondary brass and bronze production plants, basic oxygen process steelmaking facilities, sewage treatment facilities, primary copper smelters, primary zinc smelters, primary lead smelters, ferroalloy production facilities, steel plants, kraft pulp mills, glass manufacturing plants, grain elevators, lime manufacturing plants, coal preparation plants, metallic mineral processing plants, phosphate rock plants, ammonium sulphate manufacturers, asphalt processing and asphalt roofing manufacturers, residential wood heaters, non-

metallic mineral processing plants, wool fibreglass insulation manufacturers, and calciners and dryers in mineral industries.

Emissions controls have recently been developed for heavy-duty and non-road diesel vehicles. EPA has recently adopted new engine emissions and fuel standards for "heavy-duty" vehicles. Under this rule, model year 2007 heavy-duty diesel engines will be required to meet engine emissions standards for PM, NO_x, and non-methane hydrocarbons of 0.01, of 0.20, and of 0.14 grams per brake-horsepower-hour (g/bhp-hr), respectively. Gasoline engines were required to meet these standards with a phase-in of 50 percent compliance from 2007 to 2009 and 100 percent in 2009. In addition, refiners will be required to produce diesel fuel with a sulphur content of 15 parts per million (ppm) beginning June 1, 2006. EPA also adopted new regulations for "non-road" diesel engines in May 2004. The new engine standards and year of applicability vary by type of vehicle. Fuel suppliers will be required to supply diesel fuel to these equipment types with a decreasing quantity of sulphur—500 ppm starting in 2007 and 15 ppm in 2010. At the same time, EPA announced its intent to propose new engine emissions standards for locomotive and marine diesel engines.

More Stringent NO_x and SO_2 Emissions Limits have been proposed for the eastern portion of the US to address $PM_{2.5}$. A rule recently proposed by EPA, the Clean Air Interstate Rule (e.g., "Transport Rule"), seeks to reduce interstate transport of fine particulate matter to help meet the fine particle ($PM_{2.5}$) national ambient air quality standards.[2] This proposed rule does not seek to reduce direct (primary) emissions of $PM_{2.5}$. Rather, it seeks to control emissions of NO_x and SO_2, the main precursors of secondary fine particle pollution. Under the proposed rule, 29 states and the District of Columbia[3] would be given SO_2 and NO_x emissions budgets in two phases (2010 and 2015) that were determined based on pro-rata reductions of historical emissions allocations for power plants in each state. Each state would be required to revise its state implementation plan to include control measures to meet the statewide emission reduction requirements implied by the emission budgets. States would have discretion in how they meet their emissions budgets, including a choice of which sources to regulate and whether or not to use emissions trading. However, to take advantage of some of the most cost-effective emissions trading options through an inter-state cap-and-trade program, states would need to adopt EPA's model rule, which limits participation to electric generating units.

Overall, this rule would reduce NO_x emissions in the region to 1.4 million tonnes in 2010 and 1.2 million tonnes in 2015, approximately 65 percent below current levels. SO_2 emissions in the region would be reduced by 3,3 million tonnes in 2010—approximately 40 percent below current levels—and an additional 1.8 million tonnes when the rule is fully implemented—approximately 70 percent below current levels.

As in the case of the NO_x SIP Call, the design of the emissions trading program under the proposed CAIR was limited by the Clean Air Act, which gives states authority to develop plans to attain the NAAQS, the streamlined national emissions trading program under Title IV of the Clean Air Act cannot easily be replicated to meet other air quality goals. Discussions are currently underway within EPA's Clean Air Act Advisory Committee on ways to provide more federal authority to regulate sources to help states to attain the NAAQS.

[2] The program is also designed to help states achieve the 8-hour ozone standard.
[3] The state of Connecticut was found to contribute to downwind ozone pollution but not to fine particle pollution, and therefore is only required to limit seasonal NOx emissions. If Connecticut opts into the annual trading program, there would be 29 states in total, and the cap levels described above would be adjusted to reflect Connecticut's capped emissions.

3. ASSESSMENT OF EFFECTIVENESS

3.1. Environmental achievements

To understand the environmental impact of PM regulations in the EU and US, two factors are considered before and after the major air quality efforts: emissions levels and environmental impact.

3.1.1. Emissions

Both the EU-15 and the US have achieved significant emissions reductions of PM precursors—SO_2, NO_x, and NH_3. For information on the reductions in PM precursors, notably SO_2 and NO_x, see comparison on case study 1 on acidification, eutrophication, and ozone formation.

The following tables present comparative data on PM emissions for both of these jurisdictions in order to understand their respective accomplishments in reducing emissions. It is important to keep in mind that a number of factors contribute to these emissions reductions, some of which are directly related to the effectiveness of the various pieces of legislation and others that are potentially unrelated. EU-15 data are collected partly from the Eurostat and partly from EEA. US emissions data is compiled from the US Environmental Protection Agency (EPA, 2003b). The emission data are in general relatively uncertain, because the emissions vary strongly with combustion/emission conditions, and they are often based on estimates.

Table 1 presents comparative data on total emissions of primary PM_{10} and $PM_{2.5}$ from human made sources for the US and EU-15. Data are also estimated by IASA[4]: The total emissions of PM_{10} for EU were estimated for 1990, 1995 and 2010 to 2655, 1701 and 1161 (ktonnes) respectively. The total emissions of $PM_{2.5}$ for EU were estimated for 1990, 1995 and 2010 to1593, 1136 and 736 (ktonnes) respectively. The years of these estimates are not the same and there are some not explained discrepancies between the estimates and the reported emissions. These data are therefore not used in *Table 1*. There is an additional significant contribution from ships in domestic seas in Europe and the surrounding sea (Baltic Sea, Black Sea, Mediterranean Sea, North Sea and Northeast Atlantic Ocean) of approximately 115 ktonnes (EMEP, 2004). These ships also contribute to precursors (NO_x, and SO_2) of secondary particles (see case study 1).

Table 1 Total emissions of primary PM_{10} and $PM_{2.5}$ in the US and EU-15 from human made sources.[5]

		PM_{10}		**$PM_{2.5}$**	
		US	**EU-15**	**US**	**EU-15**
Total Emissions					
1990	ktonnes	2919	2843	2328	N/A
2001	ktonnes	2995	2342	2772	1206[6]
2020 (projected)[7]	ktonnes	*N/A*	*1329*	*N/A*	*881*
Reduction					
1990-2001	ktonnes	-76	531	-444	N/A
	%	-2,6	18,5	-19,1	N/A

[4] Interim Report IR-02-076. Modelling Particulate Emissions in Europe. A Framework to Estimate Reduction Potential and Control Costs. Zbigniew Klimont, Janusz Cofala, Imrich Bertok, Markus Amann, Chris Heyes and Frantisek Gyarfas

[5] Note: We have excluded certain PM emissions in order to show only human made emissions similar to what is shown for the EU-15.

[6] Estimated by EMEP.

[7] The projections for EU-15 are from "RAINS WEB (version August 2004)", http://www.iiasa.ac.at/web-apps/tap/RainsWeb/.

Overall PM_{10} emissions in both regions are relatively similar, with slightly higher levels in the US. Since 1990, both regions have witnessed small changes in emissions, when compared with levels achieved for other emissions (see case study 1). The EU-15 has seen a decrease in PM_{10} emissions since 1990 of 19 percent, while the US has witnessed an increase of 3 percent. These national and multinational totals obviously hide variations in certain portions of the two regions.

In 2001, $PM_{2.5}$ emissions in the EU-15 are less than half those in the US. While $PM_{2.5}$ trends are not available for the EU-15, the US has witnessed a slight increase in $PM_{2.5}$ emissions since 1990 of 19 percent. Since reducing $PM_{2.5}$ emissions in the US has only recently been a goal, future efforts are expected to lead to further reductions. More data collection on the part of the EU-15 will help decipher any trends in $PM_{2.5}$ emissions and enable a better comparison of trends between the two regions.

Table 2 Total emissions of PM_{10} and $PM_{2.5}$ per capita an per GDP in the US and EU-15

		PM_{10}		$PM_{2.5}$	
		US	**EU-15**	**US**	**EU-15**
Emissions per capita					
1990	*kg/person*	11,7	7,9	9,4	N/A
2001	*kg/person*	10,6	6,2	9,8	3,2
Emissions per GDP					
1990	kg/M€	634	585	505	N/A
2001	kg/M€	373	304	344	156

Since the EU-15 and US have different size populations and economies, it is also useful to consider the levels and trends of per capita and per GDP emissions (see *Table 1)*. In 2001, per capita PM_{10} and $PM_{2.5}$ emissions are lower in the EU-15 than in the US. Likewise, per GDP emissions of PM_{10} and $PM_{2.5}$ are lower in the EU-15 than in the US.

Since emissions control strategies often vary by sector, it is also useful to consider the level of progress in the energy and transportation sectors. *Table 3* presents comparative data on energy sector PM_{10} and $PM_{2.5}$ emissions for the US and EU-15.

Table 3 Energy industry emissions of PM10 and PM2.5 in the US and EU-15

		PM_{10}		$PM_{2.5}$	
		US	**EU-15**	**US**	**EU-15**
Emissions from Energy Industries					
1990	ktonnes	267	461	110	N/A
2001	ktonnes	601	409	515	75[6]
2020 (projected)[8]	ktonnes	N/A	55	N/A	37
Emissions Reductions					
1990-2001	ktonnes	-334	52	-405	N/A
	%	-124,9	11,3	-368,2	N/A
Emission Per Capita					
(1990)	kg/person	1,1	1,3	0,4	N/A
Emission per capita (2001)	kg/person	2,1	1,1	1,8	0,2

In 1990, PM_{10} emissions from the energy industry were larger in the EU-15 than in the US. Since that time, PM_{10} emissions from the energy industry in the EU-15 have declined by 11 percent while it has risen in the US by 125 percent. The rise in the US was due to the change in calculating PM emissions

[8] The projections for EU-15 are from "RAINS WEB (version August 2004)", http://www.iiasa.ac.at/web-apps/tap/RainsWeb/.

in late 90's to include condensable PM emissions: these comprise a significant portion of PM emissions, resulting in an increase in total PM emissions between 1990 and 2001. This has also influence on data for total US emissions of PM shown in other tables and figures.

$PM_{2.5}$ emissions in 2001 are estimated to be significantly lower than those in the US—515 ktonnes compared to 75. As for overall $PM_{2.5}$ data, more energy industry data collection will provide more information on trends and allow better comparison with the US.

The EU-15 has lower emissions per unit of electricity—0.1 kg/MWh—than the US, see *Table 4*. Since 1990, the EU-15 has achieved a reduction in the PM_{10} emissions rate from the energy industry—29 percent—while the US has seen its emissions rate rise—77 percent. While $PM_{2.5}$ data in the EU-15 is not currently available for the energy industry, the US rate has risen by 270 percent since 1990.

Table 4 Energy industry emissions of PM_{10} and $PM_{2.5}$ in the US and EU-15.

		PM_{10}		**$PM_{2.5}$**	
		US	**EU-15**	**US**	**EU-15**
Emissions per unit of electricity[9]					
1990	kg/MWh	0,1	0,14	0,1	N/A
2001	kg/MWh	0,2	0,10	0,2	
Reduction (1990-2001)	*%*	*-76,8*	*28,6*	*-268,1*	*N/A*

Table 5 shows comparative data on transportation emissions of PM_{10} and $PM_{2.5}$ for the US and EU-15.

Table 5 Transport emissions of PM10 and PM2.5 in the US and EU-15

		PM_{10}		**$PM_{2.5}$**	
		US	**EU-15**	**US**	**EU-15**
Transport Emissions					
1990	ktonnes	649	376	567	N/A
2001	ktonnes	485	264	411	256[10]
2020 (projected)[10]	ktonnes	*N/A*	*230*	*N/A*	*150*
Reduction (1990-2001)	*ktonnes*	*164*	*111*	*157*	*N/A*
	%	*25,3*	*29,6*	*27,6*	*N/A*
Emissions Per Unit of Travel for Passenger Vehicles					
1990	kt/(km/vehicle)[11]	0.02	0.03[12]	0.02	N/A
2001	kt/(km/vehicle)	0.01	0.02[12]	0.01	0.02[12]
Emission per capita					
1990	kg/person	2,6	1,0	2,3	N/A
2001	kg/person	1,7	0,7	1,4	0.7

While EU-15 PM_{10} emissions from transport are almost half those of the US, both regions have witnessed a similar decline since 1990 -- 25 percent in the US and 30 percent in the EU-15. While no trends are available to compare transport emissions of $PM_{2.5}$ between the two regions, transport $PM_{2.5}$ emissions are significantly higher in the US than in the EU-15. The emission per unit of travel is higher in the EU than in the US because the average mileage per vehicle is lower in the EU.

[9] Includes for the EU electricity generation and district heating. Nuclear and renewal energy production is not included.

[10] The projections for EU-15 are from "RAINS WEB (version August 2004)", http://www.iiasa.ac.at/web-apps/tap/RainsWeb/.

[11] The total emission divided by the average annual mileage of the vehicles in the fleet (i.e. the emission when the whole vehicle fleet drives 1 km). The average emission factor can be calculated by division with the total number of vehicles.

[12] Mileage and number of vehicles are from EEA (2000).

3.1.2. Environmental impact

These changes in emissions have led to concurrent changes in PM concentrations within the EU and US. *Figure 2* below shows the level of PM_{10} concentration trends in the US and EU.

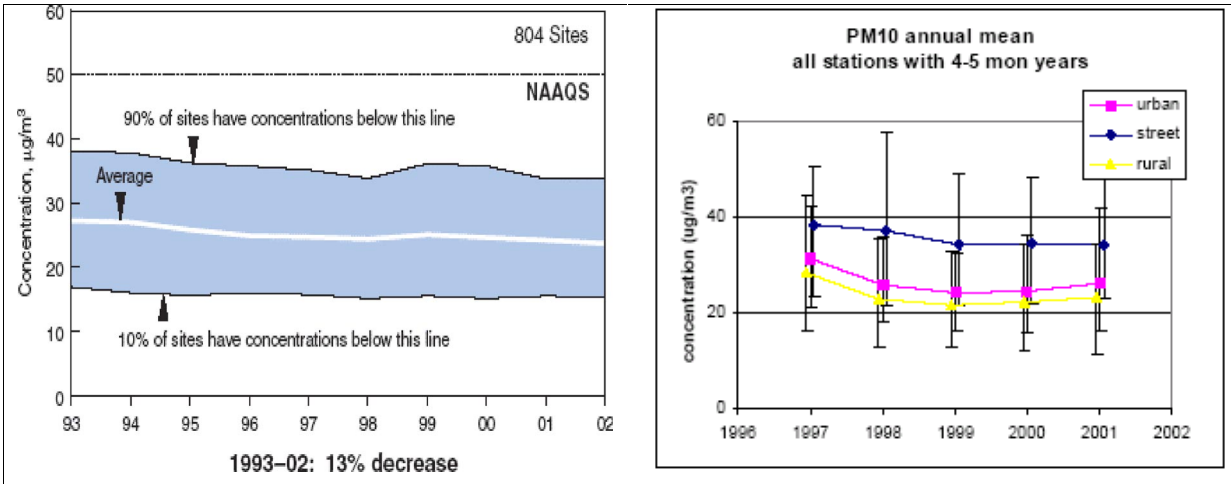


Figure 2 PM_{10} concentrations in the US and EU, annual mean average (EPA, 2004g; CAFE, 2004).

Note: For the EU, the graph includes all stations with data for 4 years. Vertical bars are 10th and 90th percentiles) respectively. The data have been collected in AIRBASE, but they are rather uncertain, because the measurement methods were not well-defined and changed in the period in the member states

Overall, the annual mean average PM_{10} emissions over the entire EU are roughly equivalent to the US levels, as can be seen in Figure 3. There is, however, some evidence that the EU has a greater share of sites that deviate from this level as can be seen by comparing the PM_{10} concentrations at which the 90 percent band is located (the blue band for the US and the bars for the EU). Both regions have made some progress in reducing PM_{10} concentrations; however, progress has been some limited in both. The US has witnessed a national decline in average PM_{10} concentrations of 13 percent between 1993 and 2002. However, progress has varied in certain portions of both regions. In western US states, programs such as those aimed at residential wood stoves and agricultural practices have helped lower PM_{10} concentrations, while in the eastern portion of the US the Acid Rain program has contributed to the decline. Likewise, the EU-15 has witnessed an overall decline since 1997, but concentrations have been relatively flat since 1999. Natural events, e.g. soil dust from nature areas (Sahara dust) and sea spray (sea salt), contribute significantly to the PM concentrations in some regions. It is estimated that the contributions from the sea and from natural mineral sources in Europe of PM_{10} are 2-11 µg/m^3 and 2-9 µg/m^3 respectively, and of $PM_{2.5}$ 1-2 µg/m^3 for both sources[13]. The Air Quality Directives permit exclusion of these contributions, if documentation is available. In some portions of the US, natural sources account for a share of total PM_{10} emissions, while others such as windblown dust and dust from unpaved roads accounts for a significantly larger share.[14]

Figure 3 shows the concentrations of PM2.5 in the US and EU-15 for 2001. As can be seen, $PM_{2.5}$ concentrations remain relatively high in both regions. The US has a number of areas with $PM_{2.5}$ concentrations above 23 ug/m^3 and some areas above 30 ug/m^3. The EU, on the other hand, has several areas above 20 ug/m^3 and no areas above 30 ug/m^3. Both the regions have a number of areas with

[13] PM characterization and sources, X. Querol et al, 2003. Presented at the Workshop on PM in Stockholm, 20-21 October 2003.

[14] See for example, www.arb.ca.gov/ei/maps/basins/abncmap.htm, where the estimated 2003 PM_{10} emissions in the North Coast Air Basin of California, natural sources accounted for less than 1 percent of PM_{10} emissions, while unpaved road dust accounted for 53 percent.

concentrations above 15 ug/m^3—the level of the US $PM_{2.5}$ NAAQS.[15] Since efforts in both regions to address $PM_{2.5}$ are relatively new, this is not surprising. Later comparisons of the trends in both, as measures are introduced, will shed greater light on the success/failure of both regions $PM_{2.5}$ efforts.

As a result of these emissions and concentrations, a relatively large population is exposed to PM_{10} in exceedance of the standards in the two regions. The PM_{10} data from EEA-31 cover approximately 68 million people in 2001, and out of these over 28 million people were exposed to PM_{10} concentration levels in excess of 50 µg/m^3 more than 36 days per year (EU limit value). In the US, approximately 8 million people lived in areas that exceeded the 24-hour mean PM_{10} NAAQS (150 µgm^3 not to be exceeded more than once per year).

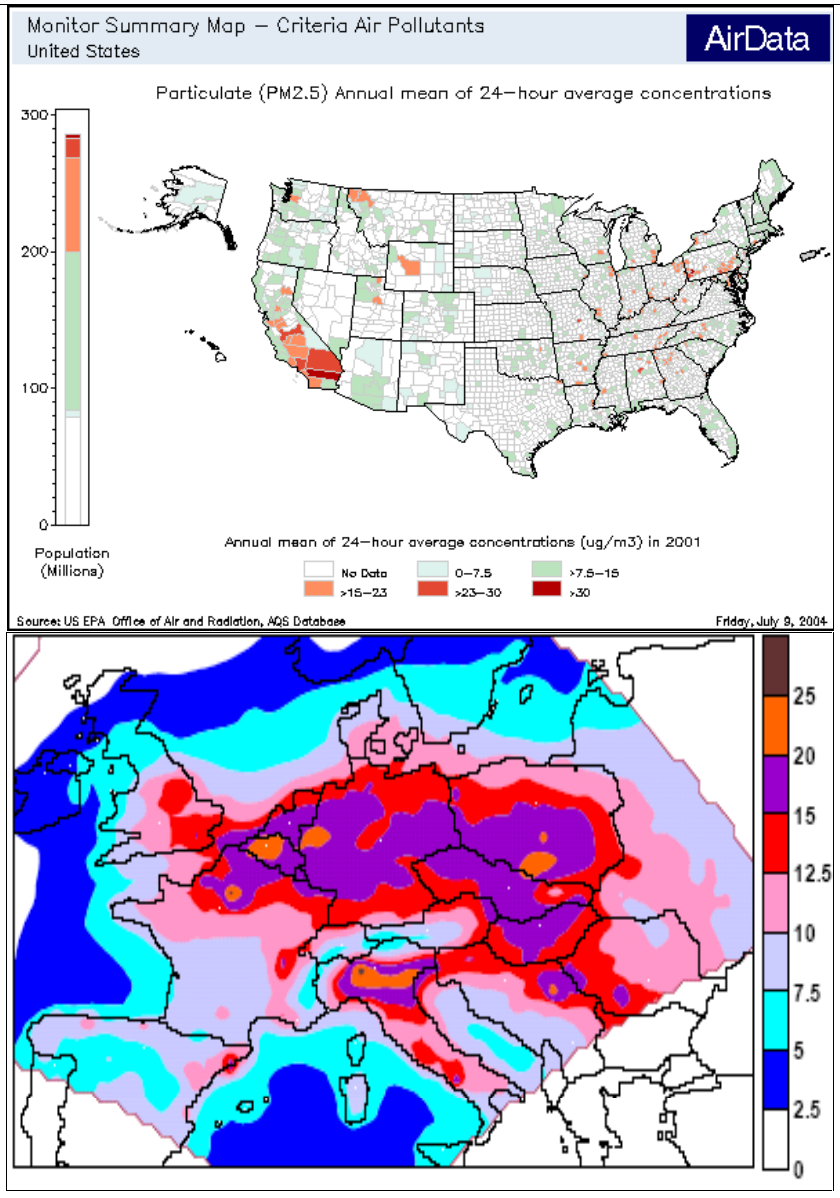


Figure 3 $PM_{2.5}$ in the US and Europe, annual mean of 24-hr avg concentrations (µg/m3) in 2001 (EPA, 2004g; NERI, 2004); Data are insufficient prior to 1999

[15] Note: it is difficult to accurately compare the areas in this category between the two figures since the US map is based upon monitored data which only shows results for areas with monitors, while the EU figure is based upon modeling data.

3.2. Costs

The costs of the emissions reductions mentioned above are another important indicator in considering the effectiveness in the two jurisdictions. Below we present summary information on the cost of the emissions reductions by considering three factors: level of technological innovation, costs versus benefits, and cost-effectiveness. Complete comparability proved difficult for a variety of reasons as mentioned earlier. Since a variety of the efforts to address $PM_{2.5}$ in the US have yet to be fully implemented, no ex-ante assessments are available. However, a limited number of ex-post analyses are available on the costs and effectiveness of specific new efforts. Below we present cost information on the ex-ante estimates for a limited number of programs.

Estimates on the costs and benefits of PM controls are difficult to come by as limited data is available. Further, a significant part of the emission reduction costs in the EU-15 and US are the cost for reduction of precursors to secondary particles, see case study 1 for more details on those costs.

3.2.1. Costs versus Benefits

While limited data is available on the costs of PM, several studies in both regions provide some values. Most of the estimated benefits of the early years of the acid rain program in the US are due to health benefits from reducing ambient levels of fine particulate matter (OMB, 2003). EPA has estimated that the non-road rule (which includes fuel requirements in addition to engine standards) will provide health benefits of $80 billion annually once essentially all older engines are replaced (EPA, 2004c). Overall costs for engine and fuel requirements are estimated at approximately $2 billion annually, yielding a cost-benefit ratio of approximately 40-to-1 (EPA, 2004c).

The total damage cost of particulate matter in the EU-15 has been estimated to be approximately 100 billion € probably dominated by the amount of secondary particles.

3.2.2. Cost Effectiveness

The estimates of the cost-effectiveness of the PM emissions reductions achieved from the US heavy-duty vehicle rule are $15.694 per tonne (EPA, 2000b). Similarly, the estimate of PM emissions reductions achieved through the implementation of the non-road diesel rule is $12.346-13.007 per tonne.

4. CONCLUSIONS

A full comparative analysis of the PM programs in the two regions was limited due to a variety of factors, including data availability and comparability, relative early stage of development of PM controls (compared with that for other pollutants), and limited ex-post analysis. Limited information was available on the Japanese and Canadian approaches, though the latter are broadly similar to the US approach. Below are some of the key conclusions from the comparison of the two regions that we were able to conduct.

- The standards comparison shows that air quality standards for PM_{10} are stricter in EU than in the US. The limit value for annual average in EU is 40 $\mu g/m^3$ to comply with in 2005, and 20 $\mu g/m^3$ (proposed) to comply with in 2010, while the US value is 50 $\mu g/m^3$. The limit value of $PM_{2.5}$ is 15 $\mu g/m^3$ (annual average) in the US. For $PM_{2.5}$ there is no limit value in the EU, but in relation to review of the PM directive limit value in the range 12-20 $\mu g/m^3$ (annual average) has been recommended in the position paper (CAFE, 2003).

- The US has an air quality limit value for $PM_{2.5}$, which has become a recent point of emphasis for air quality planning and emissions controls. As a result, a number of control strategies have been developed or proposed to address $PM_{2.5}$ in the US.

- The US has PM emissions limits for a large number of stationary sources. In the EU the LCP directive covers the PM emissions of particle precursors (NO_x and SO_2) and general guidelines are given on dust in the IPPC directive.

- PM emissions standards for light-duty and heavy-duty vehicles have been strengthened continuously since around 1990. The emission limit values in the US are in general lower than the corresponding EU emission limit values.

- Regional haze has been a focus of planning and emissions control efforts in the US, while this is not the case in the EU-15.

- Overall PM_{10} emissions in both regions are relatively similar, with slightly larger levels in the US. Greater emissions reductions of PM_{10} have been achieved since 1990 in the EU-15 than the US.

- $PM_{2.5}$ emissions for the entire economy are smaller in the EU-15 than in the US.

- EU-15 PM_{10} emissions from the energy industry are lower than in the US. Greater progress has been achieved in reducing PM_{10} emissions from the energy industry in the EU-15 since 1990—an 11 percent decline—than in the US—an increase of 125 percent.

- Energy industry $PM_{2.5}$ emissions are higher in the US than in the EU-15.

- PM_{10} emissions rates (kg/MWh) from the energy industry are lower in the EU-15 than the US. The EU-15 has achieved a reduction in the emissions rate—29 percent—while the US has seen its emissions rate rise—77 percent.

- Transport PM_{10} and $PM_{2.5}$ emissions are lower in the EU-15 than in the US. Both regions have witnessed a roughly similar decline in transport PM_{10} emissions since 1990—25 percent in the US and 30 percent in the EU-15.

- While some areas in the US have experienced reduced concentrations of PM_{10}, several areas still have concentrations that exceed the national limit values. Similarly, the EU-15 has witnessed an overall decline in PM10 concentrations.

- Only a few recent (estimated) emission data are available for $PM_{2.5}$ in the EU-15, so comparisons of emissions levels and progress with that of the US are only now possible. The US has estimated $PM_{2.5}$ data for all sources starting in 1990.

- Secondary particles are of great concern in the EU in relation to health, and the legislation is in both regions related to emissions of precursors (see Case Study 1).

- The annual mean average PM_{10} emissions in the EU are roughly equivalent to the US. There is some evidence that the EU has a greater share of sites that deviate from this average level.

- It appears that both the EU and US have a number of areas where $PM_{2.5}$ concentrations exceed 15 ug/m^3.

- While limited data is available on the costs and benefits of PM reductions, several studies in both regions provide some values. For example, in the US it has been estimated that the non-road rule (which includes fuel requirements in addition to engine standards) will provide health benefits of $80 billion annually and will cost approximately $2 billion annually. The total damage cost of particulate matter in the EU-15 has been estimated to be approximately 100 billion €. Information on administrative costs and technology innovations induced were not found.

- Estimates of the cost-effectiveness of PM were limited. Estimates in the US have found that the heavy-duty vehicle rule will cost $15.694 per tonne of emissions reduction and $12.346-13.007 per tonne for the non-road diesel rule.

CASE STUDY 4 - ANNEX 1

PARTICLE CHARACTERISATION AND HEALTH EFFECTS OF PM

4 October 2004

1. NATURE OF THE ATMOSPHERIC PARTICLES

Exposure to particulate matter has been found to be associated with increases in hospital admissions for cardiovascular and respiratory disease and mortality in many cities in Europe, in the USA and other continents (WHO, 2001 and Pope et al., 2002). The particles are also carriers of acidifying and eutrophying substances. Moreover, in virtually all areas of the US, there have been growing concerns about deteriorating visibility especially the national parks and wilderness areas, though this is a lesser concern in Europe.

Particulate air pollution is a mixture of solid, liquid and combined solid and liquid particles suspended in the air. These suspended particles vary in size, composition and origin. It is convenient to classify particles by their aerodynamic properties because: (a) these properties govern the transport and removal of particles from the air; (b) they also govern their deposition within the respiratory system and (c) they are associated with the chemical composition and sources of particles.

The atmospheric particles are ***primary particles***, which are formed during combustion, or chemical or physical processes in the engines, the combustion chamber, the industrial installation and other processes, incl. natural processes like wind erosion. The primary particles can also be defined to include particles formed immediately after the emission during the cooling process, e.g. a few tenths of a second after emission from the exhaust pipe from motor vehicles. ***Secondary particles*** are particles formed by nucleation, condensation or other processes, where gaseous pollutants or natural gases are involved in particle formation or growth.

The size of suspended particles in the atmosphere varies over four orders of magnitude, from a few Mm to tens of µm. The largest particles, called the coarse fraction (or mode), are mechanically produced by the break-up of larger solid particles. These particles can include wind-blown dust from agricultural processes, uncovered soil, unpaved roads or mining operations. Traffic produces road dust re-suspended from the road surface. Near coasts, evaporation of sea spray can produce large particles. Pollen grains, mould spores, and plant and insect parts are all in this larger size range. The brakes of vehicles produce particles in somewhat smaller sizes. Smaller particles, called the fine fraction or mode, are largely formed from gases. The smallest particles, less than 0.1 µm, are formed by nucleation, that is, condensation of low-vapour-pressure substances.

Sub µm-sized particles can be produced by the condensation of metals or organic compounds that are vaporised in high-temperature combustion processes. They can also be produced by condensation of gases that have been converted in atmospheric reactions to low vapour pressure substances. For example, sulphur dioxide is oxidised in the atmosphere to form sulphuric acid (H_2SO_4), which can be neutralised by NH_3 to form ammonium sulphate ($(NH_4)_2SO_4$). Nitrogen dioxide (NO_2) is oxidised to nitric acid (HNO_3), which in turn can react with ammonia (NH_3) to form ammonium nitrate (NH_4NO_3). Secondary sulphate and nitrate particles are usually the dominant component of fine particles. Combustion of fossil fuels such as coal, oil and petrol can produce coarse particles from the release of

non-combustible materials, i.e. fly ash, fine particles from the condensation of materials vaporised during combustion, and secondary particles through the atmospheric reactions of sulphur oxides and nitrogen oxides initially released as gases.

Figure 1 is an example from Europe illustrating the different parts of the particulates. The particle size distribution is in this figure presented in two different ways, as mass size distribution and as number size distribution. This is mainly because it is related to different types of measurement methods. It is worthwhile to mention that 1 particle with a diameter of 10 µm has the same mass as 1000 particles with diameters of 1 µm.

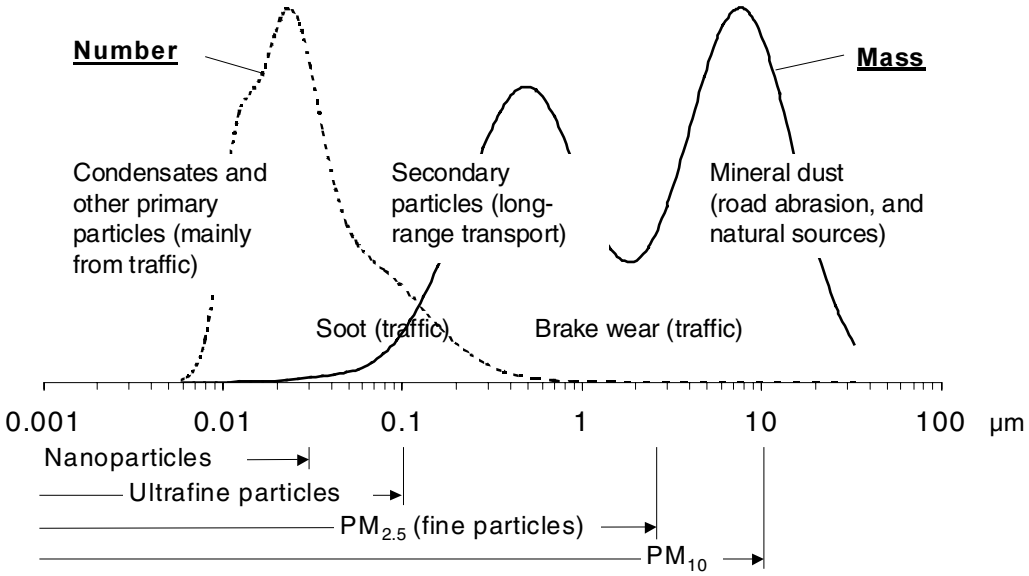


Figure 1. Mass and number distributions of PM in a busy street. The different most important contributions are shown in the different graphs (Palmgren and Wåhlin, 2004). The long range transported particles constitutes a substantial part even in large urban areas like Berlin.

The coarse particles will generally be deposited rather close to the sources, and will have a relatively short lifetime. The larger the aerodynamic diameter the closer to the source they will be deposited. The very small particles, e.g. the nano-particles, have very high mobility, which means that they will also deposit rather fast. They will also take part in the coagulation process to form larger particles. The lifetime of the nano-particles and the smallest ultrafine particles will be short. The fine and the largest ultrafine particles will have long lifetimes in the atmosphere and can be transported over thousands of kilometre. These are responsible for a major part of $PM_{2.5}$, including the secondary particles ($(NH_4)_2SO_4$ and NH_4NO_3), which contribute to acidification and eutrophication.

Because of its complexity and the importance of particle size in determining exposure and human dose, numerous terms are used to describe particulate matter. Some are derived from and defined by sampling and/or analytic methods, e.g. “black smoke (BC or soot)”, “suspended particulate matter (SPM) and “total suspended particulates (TSP)”. BC is measured as “blackness” of the particles collected on a filter by light reflection. SPM and TSP is measured by weighing of collected particles. The focus was on BC after the London smog episode in 1952, where the main source was coal burning for domestic heating and other combustion processes. Other types of particles, e.g. cement dust, require other methods, and weighing of collected particles became more common during the 1970s. Other terms refer more to the site of deposition in the respiratory tract, e.g. “inhalable particles”, which pass into the upper airways (nose and mouth), and “thoracic particles”, which deposit within the lower respiratory tract, and “respirable particles”, which penetrate to the gas-exchange region of the lungs.

The most commonly used metrics are PM_{10} and $PM_{2.5}$, but also other metrics have been considered, e.g. PM_1, $PM_{0.1}$, number of particles or surface area of the particles.

2. HEALTH AND ENVIRONMENTAL EFFECTS

Scientific studies show a link between inhalable PM (both fine and coarse particles) and a series of significant health effects. Exposure to coarse particles is primarily associated with the aggravation of respiratory conditions such as asthma. Exposure to fine particles is most closely associated with effects on breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defence systems against foreign materials, damage to lung tissue, carcinogenesis and premature death (WHO, 2003, EPA, 2003a). These smaller particles are likely responsible for most of the adverse health effects of particulate matter because of their ability to reach the thoracic or lower regions of the respiratory tract. Sensitive groups that appear to be at greatest risk to such PM effects include the elderly, individuals with cardiopulmonary disease such as asthma or congestive heart disease, and children (EPA, 2003a). European studies have indicated that ultrafine particles are of health concern (Peters and Wichmann, 2001).

Most of the investigations of the relationship between particulate matter in air and adverse health effects are based on the above mentioned very simple measured parameters, which means that until now it has not been possible to relate specific properties of the particles to the health effects. At the same time regulations of particulate matter pollution based on these simple parameters can lead to wrong or inefficient emission reduction from unimportant sources and may not regulate particles sources emitting dangerous particles.

Particulate matter can also cause adverse impacts to the environment. When suspended in the atmosphere, fine particles are the major cause of reduced visibility in parts of the United States, including the National Parks. When particles deposit onto land or water bodies, they change the nutrient balance and acidity of those environment. Particles that are deposited directly onto the leaves of plants can, depending on the chemical composition, corrode leaf surfaces or interfere with plant metabolism. Particulate matter also causes soil and erosion damages to materials, including culturally important objects (EPA, 2003b).

CASE STUDY 4 - ANNEX II

THE EU APPROACH TOWARDS CONTROL OF PARTICULATE MATTER

4 October 2004

1. PARTICULATE MATTER

1.1. Introduction

Exposure to particulate matter has been found to be associated with increases in hospital admissions for cardiovascular and respiratory disease and mortality in many cities in Europe and other continents (WHO, 2001 and Pope et al., 2002)

Particulate air pollution is a mixture of solid, liquid or solid and liquid particles suspended in the air. These suspended particles vary in size, composition and origin. It is convenient to classify particles by their aerodynamic properties because: (a) these properties govern the transport and removal of particles from the air; (b) they also govern their deposition within the respiratory system and (c) they are associated with the chemical composition and sources of particles.

Further information about the properties, transport and formation of particulate matter, effects on the environment and the health effect of particles is given in Annex 1 to the EU/US comparison.

1.2. Emissions Sources

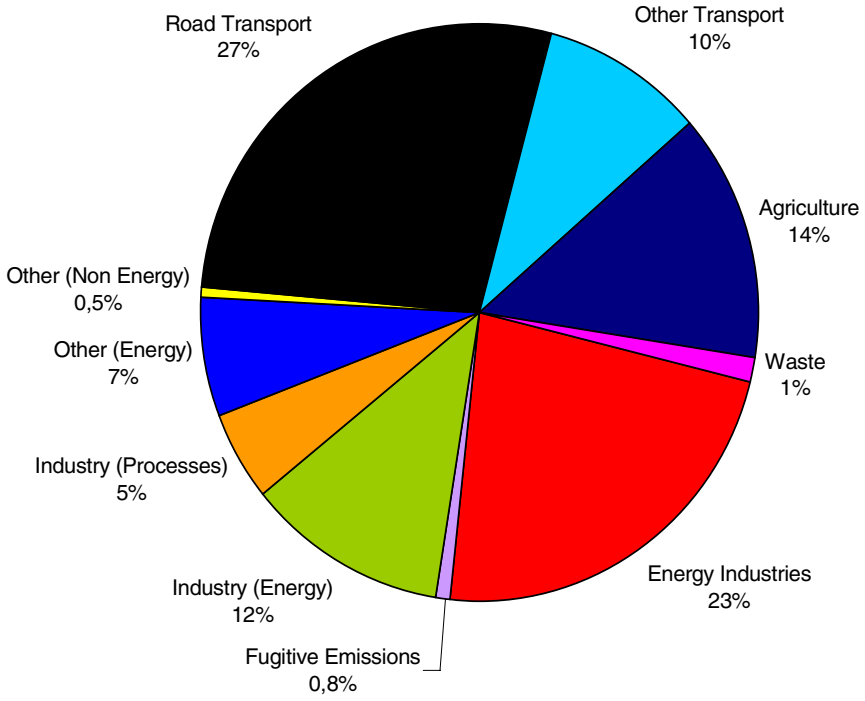


Figure 1 Relative contributions to total primary and secondary particles from different sectors in EU-15, 2001. (EEA, 2004)

The main sources to particulate matter are road transport, energy industries, agriculture, industry (energy), industry (processes), other (energy), other (non energy), other transport, fugitive emissions and waste. *Figure 1* shows the relative contributions from these sectors, including primary as well as secondary particles.

The total contribution from all sources to primary and secondary particles only related to the precursors SO_2, NO_x and NH_3 are shown in *Figure 2*.

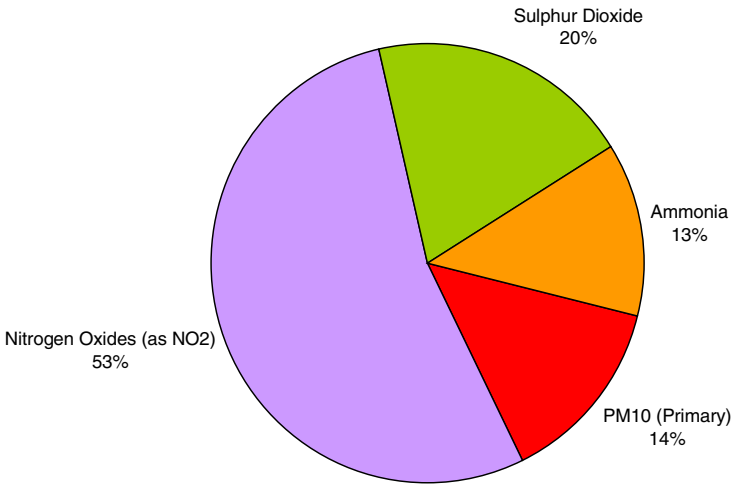


Figure 2 The relative contributions to PM10 in EU-15 in 2001 based on emissions of primary particles and calculated secondary PM10 using aerosol formation factors (NOx=0.88, SO2=0.54 and NH3=0.64 (de Leeuw). Source: EEA, 2004.
VOCs, e.g. from vegetation, can also contribute to secondary particles; they are not included here.

Particulate matter consists of primary and secondary components. Primary particles are emitted directly from sources, whereas the secondary component is formed in the atmosphere from gaseous precursors including NO_x, SO_2, NH_3 and certain VOCs. A significant part of ambient particles may at some regions result from non-anthropogenic emission sources such as wind blown crustal material (e.g., Sahara dust), sea spray (sea salt), secondary organic aerosols formed from biogenic emitted VOCs (including mono terpenes), plant debris, etc. These sources are usually not under human control and are therefore not considered here.

Figure 3 shows the relative contributions to primary and secondary particles from different sectors. It is important to notice the differences between the EU-15 countries and the accession (and new) countries; the energy sector contributes relatively more in the accession countries and the road transport relatively more in the EU-15 countries.

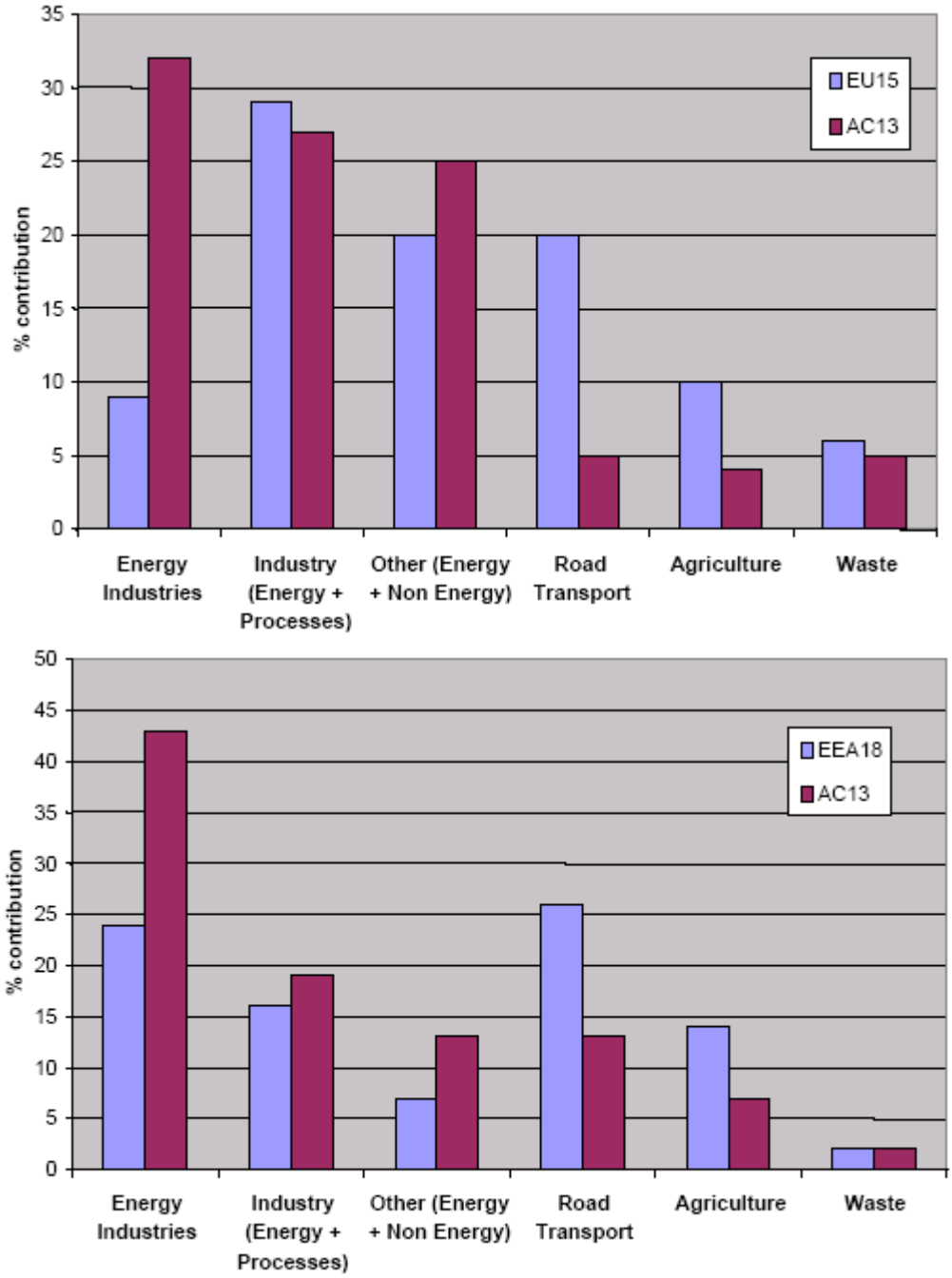


Figure 3 Primary PM10 (upper graph) and precursor gases (lower graph) from the different sectors in 2000 (EEA, 2003c).

2. LEGISLATION AND MEASURES IMPLEMENTED

The EU legislation for control of particulates consists of standards for of ambient air, and for emissions from mobile and stationary sources and on products. The following description covers how the EU legislation evolved in response to developments in scientific understanding. Only the main principles are treated.

2.1. Ambient standards

The concern about health effects of PM pollution in Europe came on the political agenda in connection with the London Smoke episode in 1952 (coal from house heating and industry). This led to development of legislation on emissions from combustion sources, especially in UK, with focus on black smoke (BS or soot). Due to severe particle pollution in the most industrialised areas during the 1970s and 1980s it became necessary - both in relation to health concern and dust nuisance - to include other parameters of the particles, e.g. the mass (suspended particulate matter, TSP), because not all types of particles are black, e.g. cement dust. The standards for air quality and control of mobile and stationary sources were mainly based on political negotiations in the EU and the national systems and with the industry.

As a consequence of the above political and public opinion, the European legislation was in 1950-1970 based on limit values on soot or black smoke (BS), which was used as an indicator of incomplete combustion, especially of solid (coal) fuel. The first EU Directive 80/779/EEC of 15 July 1980 - on air quality limit values and guide values for sulphur dioxide and suspended particulates - was implemented during the early 1980's in the Member States. The limit values of PM were on TSP and/or BS.

The concern about the health effects changed the focus to the fine particles PM_{10}, $PM_{2.5}$ or even smaller particles. The setting of limit values, control strategy etc. changed to be more impact related during the 1990s, e.g. in connection with WHO's recommendations.

In the 1990s, WHO updated its air quality guidelines (AQG) for Europe to provide detailed information on the adverse effects of exposure to different air pollutants on human health. The prime aim of these guidelines was to provide a basis for protecting human health from effects of air pollution. The guidelines were in particular intended to provide information and guidance for authorities to make risk management decisions. The European Union (EU) used the WHO guidelines as a basis to revise binding air quality limit values and target values for all EU member states through the Air Quality Framework Directive for PM. Intense investigations of health effects of particulate matter are carried out all over the world, and WHO collect the information, which forms the basis for the review and revision of the legislation under development in the framework of CAFE.

The framework Directive 96/62/EC on ambient air quality assessment and management (Air Quality Framework Directive) include PM as fine particles. This was implemented in the first daughter Directive 99/30/EC on limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air, as PM_{10}. The daughter directive is now under review and will be followed by limit values on $PM_{2.5}$, while keeping some legislation on coarse particles, i.e. $PM_{2.5\text{-}10}$ (CAFE, 2004).

2.2. Reporting and planning requirements

Commission Decision 2001/--/EC laying down a questionnaire to be used for annual reporting on ambient air quality assessment under Council Directives 96/62/EC, the Framework Directive and 1999/30/EC (2001/839/EC) require the Member States to report about air quality. Council Decision 97/100/EC establishing a reciprocal exchange of information and data form networks and individual stations measuring ambient air pollution within the Member States commits the MS to provide air quality data to the common database.

Member States' obligation is to ensure that all zones with concentrations above the limit value during the period before the attainment date reach the limit value by the attainment date. The Commission will publish every year a list of the zones above the limit value plus the margin of tolerance, and zones above the limit value. Member States must prepare detailed action plans for these areas showing how

the limit value will be met by the attainment date. These action plans must be made available to the public and sent to the Commission, which will monitor progress.

Zones where maximum pollution levels are between the limit value and the limit value plus margin of tolerance is not required to forward detail action plans to the Commission. But they must report concentrations annually to the Commission and must take any necessary steps to ensure that the limit value is met by the attainment date. Zones where maximum pollution levels are below the limit value must maintain or continue to improve their good air quality. Under the Framework Directive the Member States will report to the Commission every three years.

2.3. Measures applied to sources of emissions

The ambient air legislation was also followed up by emission legislation on different sources. Directive 88/609/EEC on the emission limits of certain pollutants into the air from large combustion plants (LCP) was replaced by Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from LCP for control of large stationary sources. They both set limits on emissions of dust. Directive 96/61/EC of 24 September 1996 on integrated pollution prevention and control (IPPC) provides a framework for controlling emissions from large industrial facilities in general, including LCPs.

It became also clear that legislation on PM/dust/BS/etc. or in general primary particles was not sufficient, because many particles were formed in the atmosphere by chemical reactions in the atmosphere with or between different precursors of which the most important were SO_2, NO/NO_2, O_3 and NH_4. Thus all of the EU air quality related legislation including the NEC Directive setting national emission ceilings in response to the Gothenburg Protocol and the EU legislation limiting the emissions of these under the CLRTAP can be viewed as aimed at controlling the PM pollution.

2.3.1. Industrial sources

According to the IPPC Directive, new and existing large industrial installations (from 2007 on) have to apply Best Available Techniques (BAT). To assist Member States in assessing BAT under the IPPC Directive, reference documents (BREFs) for certain industrial installations have been prepared by technical expert groups, which must be taken into account when authorities of Member States determine conditions for IPPC permits.

For emissions from industrial **combustion processes** control techniques are generally well established. These include electrostatic precipitators and tissue filters, scrubbers and for smaller installations also cyclones. These techniques differ substantially in their efficiency at different size fractions.

Hoods, enclosures and housings may capture fugitive emissions. In addition, systems can be installed to capture fugitive emissions. These captured streams can subsequently be ducted to an emission control system, e.g., the electrostatic precipitator, scrubber, bag house or cyclone. In addition, good operational practice to prevent or reduce fugitive losses can minimise these emissions.

Measures to reduce the emissions of PM during construction activities include the use of low emission machinery. This may also be necessary for workplace safety. Fugitive emissions may be reduced during different processes including processing, management and transport of materials (watering of materials; optimised logistic concepts; see also measures listed under unpaved roads; early paving of permanent roads); storage of materials (coverage of materials, wet suppression, chemical stabilization); deconstruction (watering). However, monitoring the enforcement of these measures is difficult.

2.3.2. Motor vehicles standards

Tail-pipe emissions are of special interest, since they almost exclusively contribute to fine PM ($PM_{2.5}$ and below). The first EU legislation was Directive 70/220/EEC on measures to be taken against air pollution by emissions from motor vehicles. It has been amended extensively over the years and was followed in the 1990s by other Directives to regulate emissions from vehicles (light vehicles: Directive 98/69/EC; heavy-duty vehicles: Directive 1999/96/EC) and fuel quality (Directive 98/70/EC). A summary of the current PM emission standards in EU is shown in *Table*

Table 1 Current PM emission standards in EU, by 2004

	EU standards	**PM emission standard**
Diesel-passenger cars and Light Duty Vehicles (LDV) GVW < 1305 kg	Euro I - 1992 / 94	0.14 g/km
	Euro II - 1996	0.08 g/km
	Euro III – 2000	0.05 g/km
	Euro IV – 2005	0.025 g/km
Diesel LDV GVW 1305 to 1760 kg	Class II – 1994	0.16 g/km
	Class II- 2001	0.07 g/km
	Class II - 2006	0.04 g/km
Diesel LDV GVW > 1760 kg	Class III - 1994	0.25 g/km
	Class III - 2001	0.10 g/km
	Class III - 2006	0.06 g/km
Diesel Heavy Duty Vehicles (HDV) and buses	Euro I - 1992, <85 kW	0.61 g/kWh
	Euro I - 1992, >85 kW	0.36 g/kWh
	Euro II - 1996	0.25 g/kWh
	Euro II - 1998	0.15 g/kWh
	Euro III - 2000	0.10 g/kWh
	Euro IV and V - 2005 & 2008	0.02 g/kWh

Control options aim at an improved combustion, fuel-quality to minimise PM emissions (e.g., low S fuels), and filtering techniques. Filtering techniques include CRT (continuous regenerating traps), which combine particle traps with oxidising catalytic converters.

Abrasion of tyres, brakes and the road surface also causes traffic emissions. However, little is known and therefore there are almost no measures at national and EU level to abate these emissions. More information on the influence of different materials and on different control techniques is needed.

Winter sanding and salting contribute significantly to PM emission from roads as do studded tires. The use of studded tires has been prohibited in several countries, but no substantial collection of data is available for assessment of the effect. Studies have been made in the Nordic countries, which show a significant contribution to PM_{10} from studded tires but no general conclusions have been drawn.

Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing. Actual control efficiencies for any of these techniques can be highly variable.

2.3.3. Off-road machinery

The EU has only limited measures on particles from off-road machinery. These consist mainly of Directives on “wheeled agriculture and forestry tractors” (77/537/EEC and amendments) and “non-road mobile machinery” (97/68/EC and amendments). Further measures are under consideration. Off-road transport control options possible for mobile road sources with diesel engines in principle also apply for off-road diesel machinery. Outside the EU more strict regulations have been implemented. In Switzerland requirements on filtering techniques have been implemented (BUWAL, 1999) and are often well suited for retro-fitting (SAEFL/BUWAL, 2004).
Railways may also contribute significantly to PM emissions. These include not only emissions from diesel driven engines, but also abrasion from brakes and tracks. Diesel emissions can be avoided by

switching to other engine types or by technical abatement measures (particle filters). Less is known about measures to reduce emissions from brake wear and tracks (BUWAL, 2002). Abatement options for ships include the switch to low sulphur fuel. In addition, an optimisation of fuel combustion conditions can reduce emissions; in principle, also secondary abatement techniques (e.g., catalytic converters and filters) are applicable.

2.3.4. Domestic sources

Small domestic combustion stoves operated with solid (coal, wood and biomass) fuels are important particle sources. There is no EU legislation on these types of sources.

Some national measures have been implemented aiming:
- Increasing the thermal standard for buildings
- Increasing energy efficiency
- Providing energy from installations with better controlled emissions (district heating)
- Use of fuels with low specific emissions (e.g., gas)
- Use of only these burning devices that are type approved, with type approval linked to compliance with certain emission standards.

Several of these possibilities have been applied in different countries, but no systematic summary of them is available and there is a significant knowledge gap.

Measures that increase energy efficiency (e.g., increasing thermal standards of buildings) will also reduce emissions of greenhouse gases (GHG). However, there is a potential conflict with measures that increase the use of renewable fuels to decrease the net emissions of GHG, since biomass (wood) burning in domestic stoves cause significant emissions of PM. Some countries (especially the Nordic countries) have regulations, e.g. type approval, of new domestic wood-burning stoves.

2.3.5. Agriculture

Reduction of emissions of the PM precursor NH_3 is potentially the most important measure in the agricultural sector. Measures to reduce PM emissions from (diesel) engines are described in the sections on transport. In addition, measures for certain processes are available:
- Abatement options in animal housing include filtering and optimised ventilation;
- Measures in the agricultural sector include a ban of stubble burning;
- Soil resuspension can be reduced by promoting plant coverage of unused fields;
- Prevention of fires in (managed) forests is necessary.

2.3.6. Other sources

Shipping gives rise to large emissions of particles and precursors to particles. However, very limited EU legislation exists for these emissions. Some countries have implemented national standards on fuel for ships and ferries operating in domestic seas. The emissions from domestic as well as from international shipping are taken into account when assessing the impact of the air pollution in especially the northern and north-western EU countries.

Aviation contributes to particles and gaseous pollutants at ground level during take off and landing. There is also concern about the contribution to ozone and particle formation during cruising, but this requires further investigations.

2.4. Measures to control long range transport of primary and secondary particles

Control options for NO_x, SO_2, NH_3 and VOCs are available and are treated elsewhere, e.g., the case studies on acidification, eutrophication and ground level ozone. The position papers, for industrial installations in the BREF documents (http://eippcb.jrc.es/pages/Boutline.htm) established under the

IPPC Directive cover primary PM emissions. The issue is also treated under the CLRTAP and its Protocols.

3. ANALYSIS OF EFFECTIVENESS

3.1. Environmental effectiveness

3.1.1. Emissions

The emissions of primary PM_{10} and PM_{10} precursors decreased significantly since 1990 see *Figure 4*. No systematic data on PM_{10} are available back to 1980 for EU-15.

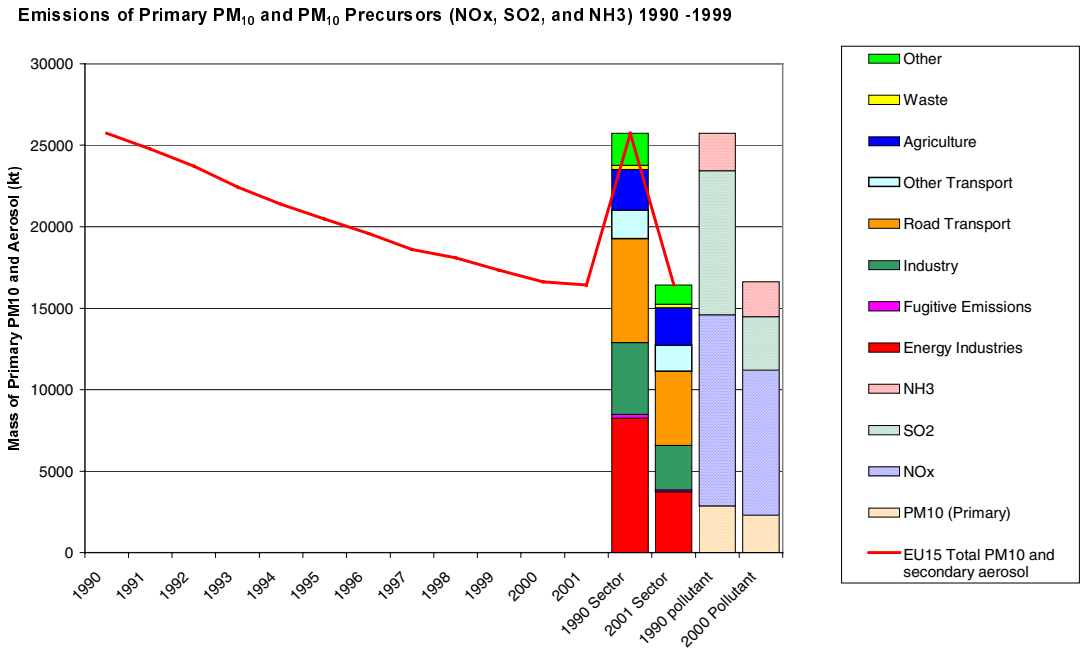


Figure 4 Emissions of primary PM10 and PM10 precursors in EU-15 in the period 1990-2001 (EEA, 2004).

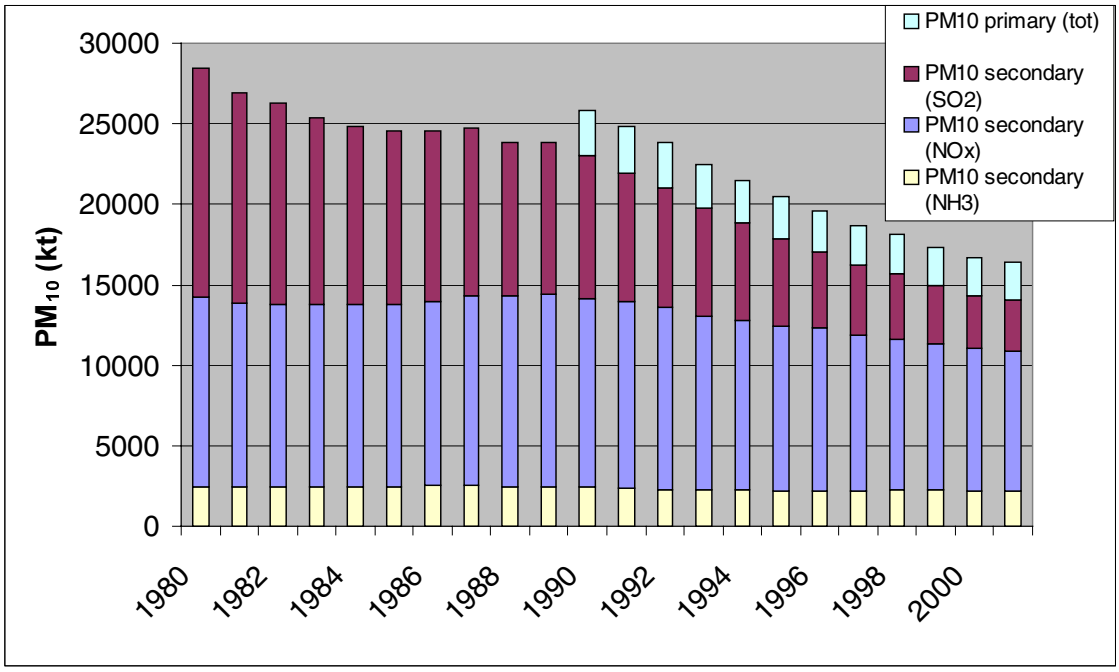


Figure 5 Primary and secondary PM10 emissions in EU-15, 1980-2000. Data source: (EEA, 2004). Emissions of secondary PM10 made using aerosol formation factors provided by ETC-AQ from "A set of emission indicators for long range transboundary air pollution" Frank de Leeuw ETC-AQ May 2000. Factors are NOx = 0.88, SO2= 0.54 and NH3 = 0.64.

The reasons for the overall downward trend are not well understood, but indications are that the trend is partially due to the success in reducing inorganic secondary particle precursor gas emissions (mainly SO_2 and NO_x). There are currently insufficient $PM_{2.5}$ data to identify any trends, although a downward trend is to be expected because of reductions in secondary particle mass.

Emissions of primary PM_{10} have been reduced between 1990 and 2001 by 18% across Europe as a whole. Figure 5 indicates that the largest reductions were obtained for secondary particles, especially those related to SO_2 emissions, with the industrial sectors achieving the greatest reductions being the energy and processing industries, probably as a consequence of the CLRTAP and the LCP Directives.

The contribution from different sectors to primary PM_{10} has been estimated under the Auto-Oil II Programme (Auto-Oil II, 2000) (*Table 2*). The contribution from road traffic is only about 10%. However, it is unclear which components of the particles cause the health effects. The relatively small fraction of the particles from road traffic can be responsible for a much larger relative contribution to the adverse health effects. The traffic particles are small and carbonaceous, which is believed to be more damaging. It should be mentioned that the non-exhaust particle emissions from traffic, e.g. particles from brakes, tires and road surfaces, are probably not fully included, or are at least uncertain. Such data is generally missing, but is needed in the future for better assessment of the impact of the particle pollution.

Table 2 EU sources to primary PM_{10} (ktonne) calculated under Auto-Oil II (Auto-Oil II, 2000).

	1990	1995	2000	2005
Agriculture	23	23	24	24
Combustion: Industry	461	437	414	390
Combustion: Non-industry	414	373	333	293
Other mobile	25	24	24	23
Processes	467	454	441	428
Road transport: Diesel	229	245	177	115
Road transport: Petrol	88	68	36	34
Road transport: Non-exhaust	33	41	47	53
Waste	100	77	53	29
EU-15	2322	2179	1939	1736
Change from 1995	-7%	0%	11%	20%

3.1.2. Environmental impact

The air concentration of PM depends very much on the location. *Figure 6* illustrates the situation in larger urban areas, e.g. Berlin. The concentration is typically highest in streets, but it is important to understand that the regional background makes up a substantial part – even in busy streets.

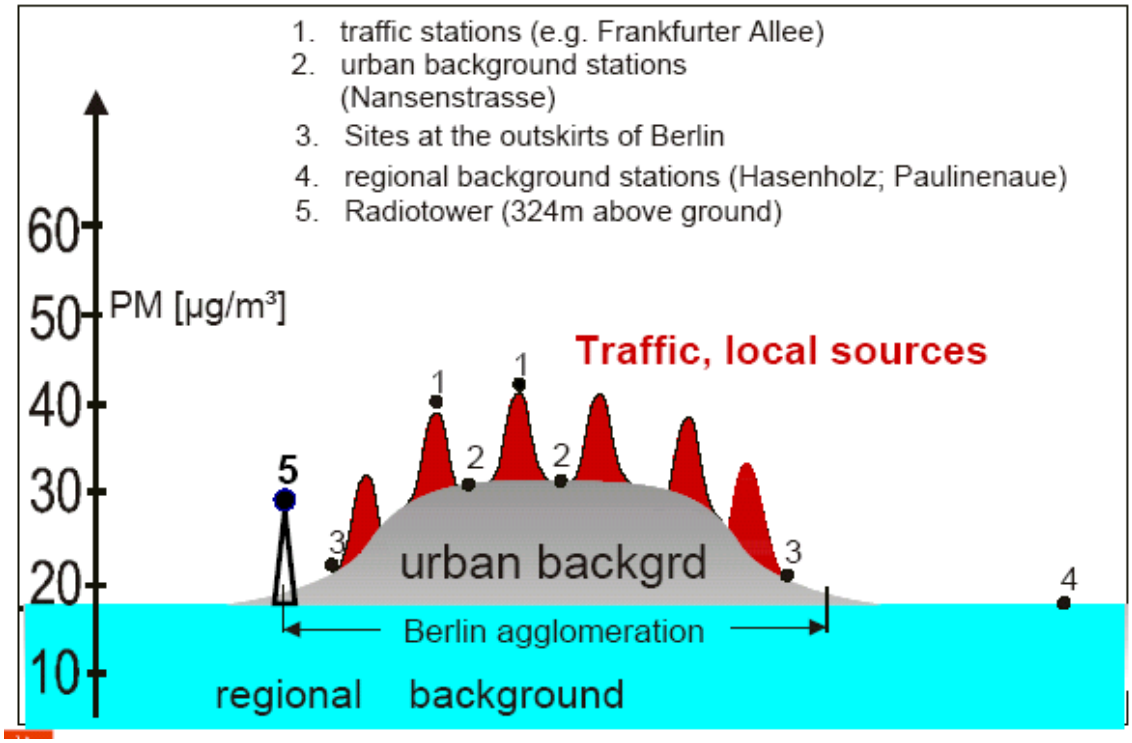


Figure 6 Schematic distribution of PM in Berlin (Lutz, 2003)

Information on PM_{10} levels, and to a lesser extent on $PM_{2.5}$ levels, has greatly improved following implementation of the Council Decision on Exchange of Information 97/101/EC and the First Daughter Directive. Information on several other metrics, notably PM_1 and ultrafine particles, is still very scarce because they are not monitored on a regular basis. The general picture is that the mass fractions PM_{10}, $PM_{2.5}$ and PM_1 are distributed somewhat more evenly in space than many other pollutants. This is due to elevated regional background levels in many parts of Europe.

Annual mean $PM_{2.5}$ levels are roughly two-thirds those of PM_{10}, but substantial variations in space and time have been reported (ranging from 40% to 80% for individual stations). The spatial distribution of $PM_{2.5}$ levels is not well known, but tends to be somewhat smoother than the PM_{10} distribution, probably due to the significant fraction of long range transported (secondary) particles. There is a tendency for lower $PM_{2.5}$ levels in Scandinavian cities. At busy traffic sites, $PM_{2.5}$ levels are typically about 40% higher than in the urban background; this is comparable to the local gradients for PM_{10}.

The majority of urban background sites met in 2001 an annual average $PM_{2.5}$ threshold of 20 µg/m³, whereas this threshold was exceeded at traffic-exposed sites in 15 out of 23 cases.

The scarce data on PM_1 indicate that the levels are typically about half of PM_{10}. There is evidence that the concentration of ultrafine particles varies much stronger spatially, with a range of an order of magnitude going from rural to hot spot levels.

PM_{10} data in AirBase[16] show that on the average over some 190 stations with data for the years 1997-2001, there was a decreasing tendency from 1997 to 1999, and a slight increase between 1999 and 2001. For the period as a whole, the concentrations were reduced by about 15-20%, somewhat less for the annual average than for the 36th highest 24-hour concentration. This pertains to all three types of stations considered (rural, urban, street). Although the majority of the stations have a downward tendency (for most, this tendency is non-significant, at 90% confidence level), about 20% of the stations have an increasing tendency (mostly street and urban background stations) (*Figure 7*).

The reduction in rural secondary inorganic aerosols (sulphate and nitrate), as assessed from EMEP data, is of the same magnitude as the measured PM_{10} reductions. Taking into account the influence of interannual variations in meteorological conditions, which have not been accounted for, and also the relatively few stations (about 190) with long enough time series to be included in the analysis, one should be careful to attach significance to the indicated 15-20% reduction as a representative average figure for the European area in 1997-2001. The decreasing tendency occurs mainly in the early part of this period; with a tendency to increase appearing in the later part of 1997-2000. There is also evidence from several countries (e.g. Germany, Belgium, Czech Republic, and Switzerland) that PM_{10} concentrations in 2002 and particularly in 2003 show an increase. Although this increase is mainly due to meteorological conditions, it cannot be excluded that increasing emissions in some parts of Europe may play a role as well.

[16] The European air quality information system under European Topic Centre on Air and Climate Change. http://etc-acc.eionet.eu.int/databases/airbase.html

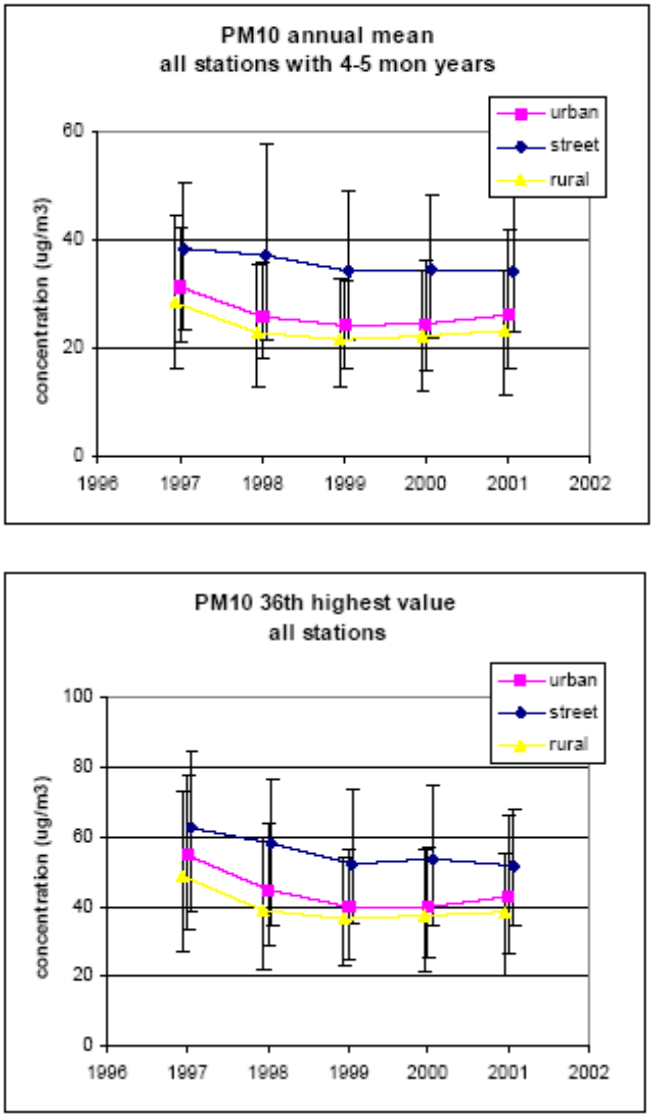


Figure 7 PM_{10} interannual variations, 1997-2001. Annual mean and the 36th highest daily value per year (both are EU limit value indicators). The graph includes all stations with data for 4 years. Vertical bars are 10th and 90th percentiles (CAFE, 2004).

Although it seems clear that concentrations have indeed been reduced in most of Europe before 2000 – and this can be explained at least partly by abatement of sources, particularly large combustion sources resulting in significantly reduced emissions e.g. of precursors of secondary PM – the extent of PM_{10} concentration reductions in Europe still cannot be accurately quantified.

The results from analysis of the AirBase data are backed up by PM data from the EMEP database. Both AirBase and EMEP data indicates that PM_{10} is not reduced throughout all of Europe. For examples, Spain and Switzerland have largely unchanged levels over the analysed period. However, from analysis of national trends, there is evidence that, PM_{10} concentrations in the Netherlands have been reducing on average by 2 to 3% per year over recent years (1993-2002), after correction for variations due to meteorological conditions.

3.1.3. Visibility

Change in visibility is a function of particle concentration and in the USA this is considered as a serious loss of amenity. However, the issue of impaired visibility is not yet considered a serious

problem in Europe. Once recent analysis carried out for DG Environment and the UNECE, and concluded that this is possibly because reduced visibility through poor air quality is now less of a problem than it was a few years ago. The study concluded that the US situation could not be generalised to Europe (Holland & Watkiss, 2000).

3.1.4. Human exposure

Human exposure to particles has been monitored for a number of years. *Figure 8* shows the number of days with high particles concentrations in urban areas in Europe. There is no discernible trend and large interannual variations. The number of days with high concentrations is highest for "hot spots", e.g. streets, indicating a significant contribution from traffic.

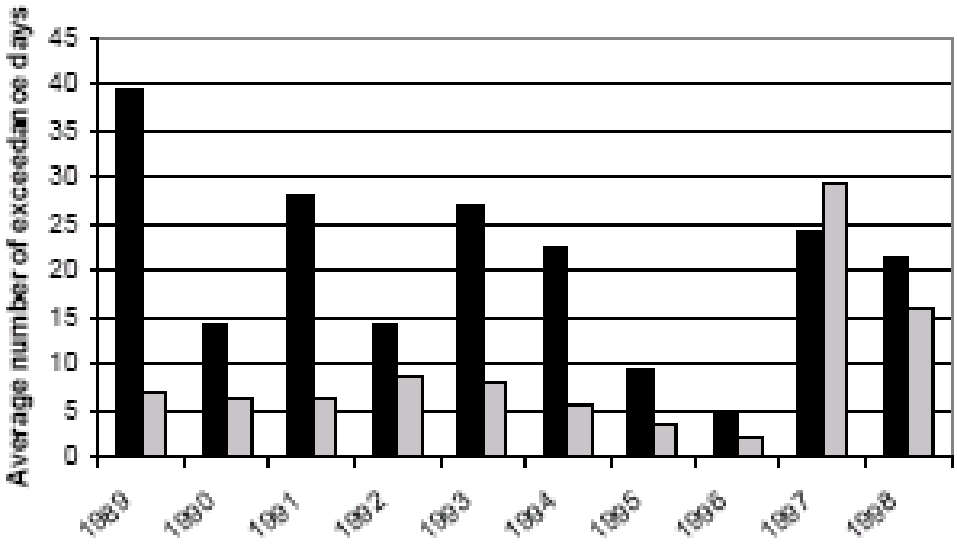


Figure 8 Average number of exceedance days in urban areas (black smoke 24h >125, TSP 24 h > 120, PM_{10} 24h > 50 ug/m3). Black columns: Urban sites, excluding urban background sites: Open columns: Urban background sites.

Figure 9 shows the number of people exposed to high particle concentrations, which seems to be increasing. However, the number of monitoring stations is also increasing, which could influence the number.

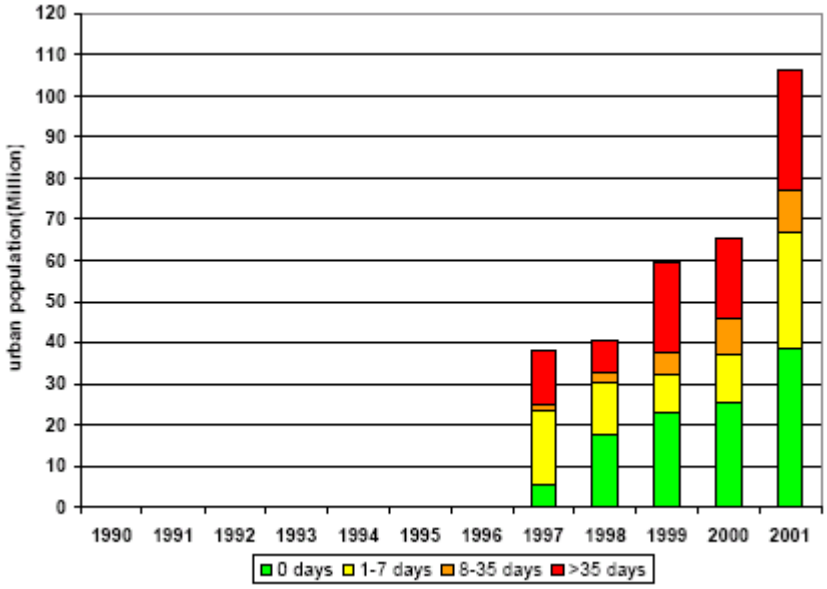


Figure 9 Population in cities according to concentration range, "max 36" exposure of urban population in EEA-31 exceedance days with daily mean 50 µg/m^3. NB: For the years before 1997, representative monitoring data are not available. Year-to-year variations in exposure classes are partly caused by the change in spatial coverage. Source: Air quality database AirBase (ETC/ACC).

3.2. Costs

3.2.1. General considerations

There is no simple answer on the cost effectiveness of measures, since this depends crucially not only on the availability and effectiveness of measures, but also on the PM metric under consideration, the scale (e.g. local hot spot versus urban or regional background) and the objectives (e.g., compliance with limit value versus reduction of health impact). Source apportionment studies have shown the important contributions of secondary inorganic aerosols from NO_x and SO_2 emissions and primary emissions from traffic to ambient PM levels. In addition, WHO has identified traffic and other combustion sources as critical to health impacts, e.g. related to carbonaceous particles.

The cost-effectiveness of measures depends on several different issues like the contribution of different sources to pollution levels, the reduction potential and the costs of additional measures. In addition, it is necessary to define the metric under consideration (like TSP, soot, PM_{10}, $PM_{2.5}$ or ultrafine particles, the fine and ultrafine requiring more emphasis on controls over combustion sources), the scale of the problem (reduction of the background level versus reduction of hot spot concentrations), and the objective to be achieved (compliance with LV at hot spots; reduction of health effects).

Few studies have been conducted to investigate the cost-effectiveness of different measures specifically related to particles. However, studies can be found concerning measures related to particle precursors. In general, studies are hampered by uncertainties in emission estimates, problems in modelling PM levels accurately and uncertainty on the efficiency of measures, in particular on those affecting non-combustion sources.

Section 3.1.1.of this case study already gave an overview of the main emission sources of primary PM and secondary PM. In addition, there is a clear relationship between past measures and decreasing trends in PM levels in ambient air, demonstrating the efficiency of several measures already taken. The removal efficiency of the different measures to control emissions from combustion sources is usually well established. The size fraction affected depends on the sources characteristics and the measure applied, but mainly the fine fraction is affected.

For non-combustion sources, numerous measures have also been described and tested, even though studies showing the quantified effects of such measures are scarce. However, the overall importance of these sources is decreased if the metric of interest is ultrafine particles, $PM_{2.5}$ rather than PM_{10}.

In general, a large potential for further reductions exists for precursors of secondary aerosols, in particular for SO_2, but also NO_x, NH_3 and VOCs. The results for reduction potentials on top of current legislation scenarios for primary PM are somewhat conflicting. However, in general, larger reduction potentials for primary PM on top of current legislation can be expected for Accession Candidate Countries and other non-EU countries compared to current Member States.

The highest exceedences occur in hot spot locations such as traffic - related sites and industrial sites. In addition, the source apportionment points at strong contributions from long-range transport and traffic sources, and sometimes industrial sources. These sources will have to be addressed to affect PM levels significantly. In addition, it has to be kept in mind that the advice given by WHO suggests that tailpipe emissions from traffic and other combustion sources are critical sources in terms of health effects. This is a clear indication that combustion sources should be considered with some priority when assessing abatement strategies. In terms of exposure, those sources are of most interest which gives rise to high concentrations in areas where people are likely to be exposed, such as road traffic within cities.

An assessment of the reduction in a large agglomeration in Western Europe confirmed that measures to reduce local sources, in particular exhaust particles from road traffic, had a limited effect on total PM_{10} concentrations even at urban hot spots. This is because the PM_{10} concentration is dominated by non-exhaust particles (from road surface, tires, brakes, winter sanding etc) and long range transported (secondary) particles. However, the exhaust particles contribute to the ultrafine, carbonaceous particles.

Much more information on local and regional measures, their costs and their effectiveness can be expected in the coming years, covering *inter alia* as Members States gain experience in implementing the first air quality Daughter Directive (1999/30/EC).

3.2.2. Findings from a study in the UK and from the EU Auto-Oil Programme

In the United Kingdom, an Interdepartmental Group on costs and benefits has investigated a number of measures on the industrial, domestic and transport sector (DEFRA, 2001). Overall, the transport measures in the package appeared to be less cost effective than many of the potential industrial measures in terms of reducing background PM_{10} concentrations. However, it was found that the transport measures were better targeted at reducing roadside concentrations and were more effective at this than the industry measures in London, where the highest roadside concentrations are found. The Group concluded:

> "The analysis has considered a range of techniques for reducing PM10/particles emissions, and their relative contributions to reductions in population weighted concentrations, from both transport and non-transport (stationary) sources. Costs have been estimated for an illustrative package of measures leading to a 0.751µg/m3 reduction in population weighted concentrations in 2010. The analysis has also considered the health and non-health benefits associated with such a reduction and have included the full range of potentials for long term health effects of exposure to particles as referred to by COMEAP in their recent statement. Due to a lack of agreed estimates of willingness to pay to avoid the risks associated with air pollution, the health benefits have not been expressed in monetary terms. It is therefore difficult to come to precise conclusions regarding the balance of costs and associated chronic mortality benefits. However, the analysis shows that:
>
> - the non-zero estimates of chronic mortality benefits potentially dominate all the other categories of benefits that have been quantified;

- the 'cost of added life year' implied by the cost estimates and life years gained is in a range which is consistent with the valuation of risks to health or prevention of a fatality in other policy/regulatory contexts.

Whilst these results relate to the illustrative package of abatement measures and the central benefits scenario, it is important to take account of the uncertainties in the costs and benefits, especially when assessed over the long-term. This report provides sensitivity analysis on the uncertainties throughout and which are summarised in the main section comparing the costs and benefits. The key uncertainties relate on the benefits side to the quantification of chronic mortality effects of exposure to particles and on the cost side to the sensitivity of the annual cost estimates and the choice of discount rate. It is emphasised that the information available for this assessment is highly uncertain. Ranges of estimates have therefore been put forward, in line with expert advice, rather than single figures which might give an unjustified impression of certainty in the results. However, qualitative estimates of the plausibility of the various out-comes are given wherever possible. Any single figures or narrow ranges given in summaries should be regarded as a general guide rather than a precise estimate."

Similarly, a study carried out for the European Commission's Auto-Oil Programme estimate of different scenarios for reducing emissions from motor vehicles, related to different measures for petrol and diesel vehicles.

Due to the limited availability of technology and implementation cost data and the lack of proper validation platforms, no strong conclusions could be drawn in terms of cost-effectiveness. Nevertheless, it was concluded that the significant emission reduction potential of local schemes suggests that they could be more cost-effective than EU wide measures, in particular in view of fewer EU-wide air quality problems and more regional differences in emission source categories as predicted by the AOP-II air quality experts.

3.2.3. Control costs in Europe

Assessments of control costs before 1990 are scarce. In order to illustrate the order of magnitude an example from an ex-ante study related to the NEC Directive will be used Ina baseline scenario 1990-2010, the total cost for Europe was found to be 89 billion €/year in 2010, with the cost distributed as shown in Table 6. Western Europe was expected to bear 81% of the cost due to more stringent emission ceilings than the other parts of Europe. It should be noted that this study did not fully take into account the changes in Central and Eastern Europe that would occur as a result of accession measures, including adoption of the EU environmental standards.

Table 6 Annual emission control cost for the baseline study (1995 prices) (IIASA, RAINS model)

	Cost billion €/year	Distribution of control cost (%)				
		NO_x+VOC stationary	SO_2	NH_3	PM_{10}	Mobile sources
Western Europe	72	11	22	1	8	59
Central and Eastern Europe	14	2	14	7	15	61
Russia and EECCA	3	2	35	1	63	0
Total	89	9	21	2	11	57

3.2.4. External costs of emissions

The external costs of emissions were estimated in a study carried out using the economic model, BeTa (Holland and Watkiss, 2000).

The study concluded that human health effects cause the major part of the external costs, and the particle effects are dominating. The cost estimates are rather uncertain, first of all because the relationship between air pollution and health effects is uncertain. Only PM_{10} and $PM_{2.5}$ are considered, but there is some indication that other parameters of the particles are more closely related to the health effect (number, surface, chemical composition etc.). However, at the moment there is no sufficient data, which can be used for an economic evaluation.

CASE STUDY 4 - ANNEX III

THE US APPROACH TOWARDS CONTROL OF PARTICULATE MATTER

4 October 2004

1. UNITED STATES PARTICULATE MATTER APPROACH

1.1. Introductory Overview

Efforts to address particulate matter (PM) have taken place relatively later in the US compared to other criteria pollutants, and much of the focus had been on PM_{10} until recently. The U.S. Clean Air Act addresses particulate matter in a similar way to ozone formation, by establishing NAAQs and requiring the development of State Implementation Plans (SIPs) to meet those ambient health-based standards. In addition, efforts have also been focused on controlling regional haze.

1.2. Sources of Emissions

Direct PM emissions are generally examined in two separate groups. The first group is composed of the more traditionally inventoried sources, such as fuel combustion, industrial processes, and transportation. The second group is a combination of miscellaneous and natural sources, including agriculture and forestry, wildfires and managed burning, and fugitive dust from paved and unpaved roads. In general, miscellaneous and natural sources account for a much larger percentage of total PM emissions nationwide than the traditionally inventoried sources.

In 1990, miscellaneous and natural sources accounted for approximately 88% of total direct PM_{10} emissions nationwide, while the traditionally inventoried sources accounted for only 12% (see below). During the same year, miscellaneous and natural sources accounted for approximately 69% of total direct $PM_{2.5}$ emissions nationwide, while fuel combustion, industrial processes, and transportation accounted for 12%, 11% and 8%, respectively (EPA, 2003b).

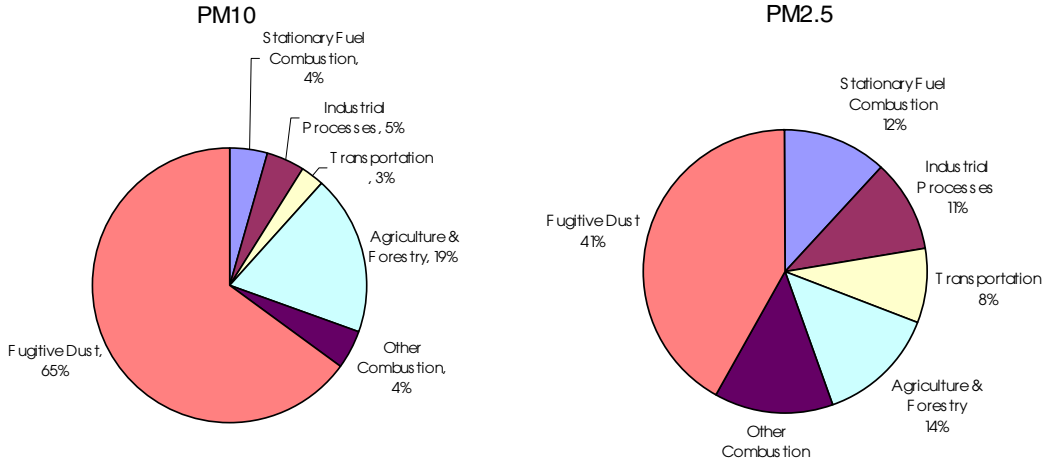


Figure 1. U.S. national average emission categories for PM10 and PM2.5 in 1990 (EPA, 2003b)

2. LEGISLATION AND MEASURES IMPLEMENTED

Implementation of the CAA guidelines to address PM in the U.S. have been undertaken in four separate, yet intertwined manners – National Ambient Air Quality Standards (NAAQS), State Implementation Plan (SIP) process for PM_{10} and $PM_{2.5}$, regional haze program, and SO_2, NO_x, and PM emissions controls programs under the Clean Air Act (CAA).

2.1. Air Quality Limit Values: National Ambient Air Quality Standards

Separate NAAQS have been established in the U.S. for PM_{10} and $PM_{2.5}$ with different timelines and requirements for compliance.

2.1.1. PM_{10}

The first NAAQS addressing PM were set in 1971, using total suspended particulate (TSP) as an indicator to represent particles of all size suspended in the ambient air. TSP NAAQS specified that the annual mean TSP concentration was not to exceed 75 $\mu g/m^3$, and that 24-hr mean was not to exceed 260 $\mu g/m^3$ more than once a year (EPA, 1987). In 1979, EPA announced its first periodic review of TSP standards as NAAQS for PM, and significant revisions to the original standards were made in 1987. In that decision, EPA adopted a new indicator, PM_{10}, and established new primary and secondary NAAQS of both short- and long-term standards. The primary, or health-based, short-term (24-hour) standard of 150 $\mu g/m^3$ is not to be exceeded more than once per year, on average, over 3 years. The primary long-term (annual) standard requires an expected annual arithmetic mean not to exceed 50 $\mu g/m^3$ averaged over 3 years (EPA, 2003c). The secondary, or welfare-based, standards are identical to the primary standards.

The 1990 CAA Amendments specified substantive requirements and attainment deadlines for PM_{10} state implementation plans (SIP), and classified PM_{10} nonattainment areas into moderate and serious areas.[17] Moderate areas were required to adopt a permit program for new and modified sources, implement Reasonably Available Control Technology (RACT) for existing sources, and demonstrate attainment by the end of 1994 or no later than the 6th year after designation. Serious areas were required, in addition, to implement Best Available Control Measures (BACM) for existing sources and Lowest Achievable Emission Rate (LAER) for major new or modified sources and demonstrate attainment by 2001 or no later than the 10th year after designation.[18]

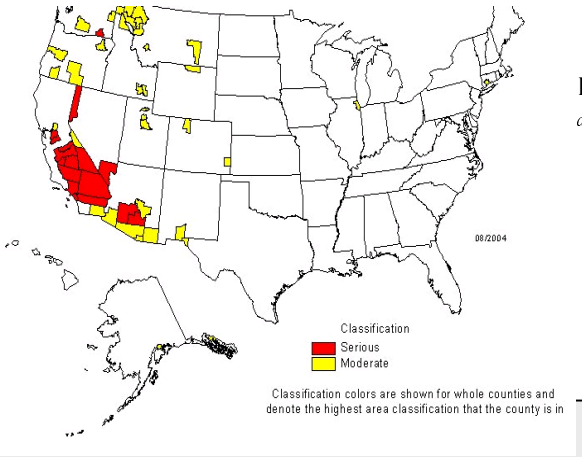
2.1.2. $PM_{2.5}$

Since the establishment of PM_{10} NAAQS in 1987, a large number of epidemiological studies have observed adverse public health effects associated with exposure at levels well below the PM_{10} standards (EPA, 1997b). These effects included premature mortality, hospital admissions, and respiratory illnesses. As a result, EPA began to review the PM_{10} standards in 1996, and proposed revised PM standards in 1997 (see Box 1 for an overview of the process).

Box 1: Overview of US Process for Establishing the $PM_{2.5}$ Standard (NAS, 2004)

The process to review and update NAAQS for PM followed the process for other pollutants which involves input from independent scientific bodies and the general public (for a schematic of this process see NAS, 2004 figure 2-1). EPA's Office of Research and Development prepared a detailed document, a "criteria document", with input from inside and outside the Agency that includes details on emissions sources, exposure, and health and welfare effects based upon existing scientific and technical information.[19] EPA's Office of Air Quality Planning and Standards then prepared a "staff paper", which recommends and provides justification for the EPA administrator to make revisions to the current standard.[20] Both documents were provided to the public for comment. The Clean Air Act Scientific Advisory Committee reviewed the criteria document, staff paper, and public comments and suggests revisions. Once satisfied, the Committee informs the Administrator that the documents fully and fairly represent the current state of science. The Administrator then publishes a proposed new or revised NAAQS.

[17] CAA § 188, 189 and 190.
[18] See below for more details on BACT, BACM, and LAER.
[19] The criteria document for PM is available at: www.epa.gov/ttn/oarpg/t1cd.html
[20] The staff paper for PM is available at: www.epa.gov/ttn/oarpg/t1sp.html



In addition to retaining the PM_{10} standards, EPA added a new annual $PM_{2.5}$ standard set at 15 µg/m^3 and a 24-hour standard set at 65 µg/m^3 to increase level of protection against the PM-related health effects.[21] In developing a suite of $PM_{2.5}$ standards, EPA considered several factors including averaging times, form of the standards, and standard level (see Box 2 for more detail).

Averaging Times. EPA considered the combined effect of the standards rather than an approach that weighted short- and long-term exposure evidence, analyses, and standards independently (EPA, 1997b). EPA concluded that much of the total annual risk associated with short-term exposures is likely to result from days when the PM levels are in the low- to mid-range, below the 24-hr peaks. As a result, lowering a wide range of $PM_{2.5}$ concentrations through an annual standard, as apposed to focusing on controlling peak 24-hour concentrations, was the best way to reduce total $PM_{2.5}$ risk (EPA, 1997b). The 24-hr standard was rather to provide additional protection for days with high $PM_{2.5}$ concentrations in localized hot spots and risks from seasonal emissions, such as wood smoke in the winter.

Form of the Standards. In order for areas to be in compliance with the annual $PM_{2.5}$ standards, the 3-year average of the annual arithmetic mean $PM_{2.5}$ concentrations, from single or multiple community-oriented monitors, must be less than or equal to 15 µg/m^3 (EPA, 1997b). The use of single or multiple community-oriented sites was to consider the relationship between the area-wide health statistics to averaged measurements of the area-wide air quality. Alternatively, the 24-hr $PM_{2.5}$ standard is based on the 98th percentile of 24-hr $PM_{2.5}$ concentrations in a year (averaged over 3 years) at the population-oriented monitoring site with the highest measured values in an area (EPA, 1997b). This form was selected to reduce the impact of a single high exposure event that may be due to unusual metrological conditions, where as the percentile form was to compensate for missing data or less-than-everyday monitoring.

Standard Level. The annual $PM_{2.5}$ standard level of 15 µg/m^3 was established based on the evidence that adverse health effects at such a level is highly uncertain and the likelihood of significant health risk becomes smaller at concentrations well below the 15 µg/m^3 level (EPA, 1997b). The 24-hr $PM_{2.5}$ standard level of 65 µg/m^3 was to supplement to the annual standard and to provide an adequate margin of safety in communities that meet the annual standard but have infrequent or isolated 24-hr peaks.

2.2. State Implementation Plans

Similar to other criteria pollutants, once PM NAAQS are finalized, areas are designated into attainment and no attainment and states undertake a SIP process to meet the NAAQS. The PM SIP process has been undertaken for PM_{10} and $PM_{2.5}$, with each at different phases in the process. See case study 2 for details on the SIP process.

2.2.1. PM_{10}

Subsequent to the adoption of PM_{10} NAAQS, EPA designated no attainment areas and classified them into moderate or serious (see Figure 2). States developed SIPs and submitted these for approval to EPA.

[21] For technical detail, see EPA (1997).

Figure 2. U.S. Nonattainment Areas for PM_{10}

2.2.2. $PM_{2.5}$

Since the promulgation of the $PM_{2.5}$ NAAQS, EPA has been developing implementation rules. In 2003, EPA issued guidance for state and local agencies on the area designation process. EPA also announced that it plans to make final area designations by December 2004, based on the air quality data from the years 2001-2003. In the meantime, EPA is expected to announce final $PM_{2.5}$ NAAQS implementation rules, as well as a review of 1997 $PM_{2.5}$ standards and 1987 PM_{10} standards.

2.3. Regional Haze

In addition to the health-related issues, there was growing concerns about deteriorating visibility in virtually all areas of the US, especially national parks and wilderness areas (see Figure 3). In response, the 1977 CAA Amendments established a national goal of preventing and remedying visibility impairment due to anthropogenic pollution in Class I areas, which included most of the 156 national parks and wilderness areas.

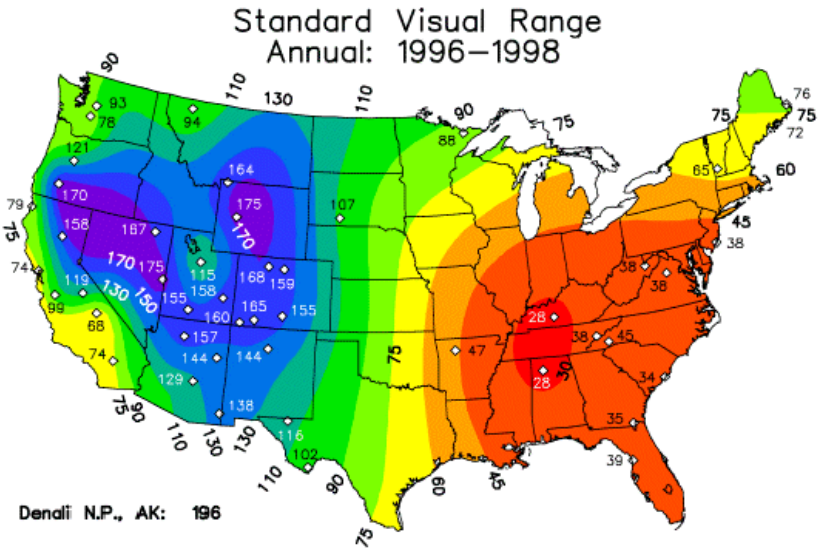


Figure 3. Standard visual range for the period 1996-1998 in units of kilometres (VIEWS, 2004).

The 1990 CAA Amendments required EPA to establish regulations to ensure "reasonable progress" in improving visibility in Class I areas.[22] The Amendments required EPA to work with several Western States to establish a Commission to address visibility in the Grand Canyon National Park and to take

[22] CAA § 169(a).

regulatory action on regional haze within 18 months of receiving the Commission's recommendations. Subsequently, the Grand Canyon Visibility Transport Commission (GCVTC) was established in 1991, and the Commission reported its recommendations to EPA in 1996.

In 1999, EPA promulgated the Regional Haze Rule which established a 65-year program to return Class I areas to their natural visibility conditions (EPA, 1999c). Because of evidence that fine particles are frequently transported over long distance, all 50 states – including those without Class I areas – were required to participate in planning, analysis, and emission control programs. All but the nine western states participating in the GCVTC were required to determine their individual "reasonable progress" goals that would accumulatively achieve natural visibility conditions by 2064 (see box 3). States were required to develop long-term (10 to 15 years) implementation plans that include enforceable measures on all types of anthropogenic sources, including mobile, stationary and area sources and prescribed fires.[23] In developing these plans, States could take into account the emission reductions due to promulgating the attainment-demonstration SIPs for NAAQS.

Box 3: Grand Canyon Visibility Transport Commission and the Western Regional Air Partnership

The Western Regional Air Partnership (WRAP) was formed in 1997 as the successor to GCVTC, consisting of nine states and eleven Native American tribes that were exempt from developing long-term goals under section 309 of the regional haze rules. Instead, these states – Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah and Wyoming – were required to implement the strategies recommended by the GCVTC in 1996. In 2000, WRAP submitted an annex to the 1996 GCVTC report to EPA, proposing regional emissions reduction milestones for each year between 2003 and 2018 through a shrinking SO_2 emissions trading program. WRAP expects the emissions cap to be met through voluntary measures; thus the trading program serves as a "backstop" in case the voluntary measures are not sufficient (NRC, 2004). In 2003, EPA approved the annex.

States were encouraged to work collaboratively with other states by forming regional planning organizations (RPOs). With funding from EPA, five RPOs were formed to evaluate technical information to understand their impacts on Class I areas and to develop appropriate regional strategies. These RPOs are: Western Regional Air Partnership (WRAP); Central States Regional Air Partnership (CENRAP); Midwest Regional Planning Organization (Midwest RPO); Mid-Atlantic/Northeast Visibility Union (MANE – VU); and Visibility Improvement State and Tribal Associations of the Southeast (VISTAS) (See Figure 4).

[23] Because of the purpose of prescribed fires is to restore the natural fire cycle to forest ecosystems, EPA announced to work with States and Federal Land Managers to support development of enhanced smoke management plans to minimize the effects of fire emissions on public health and welfare (EPA, 1999d)

Figure 4. Regional planning organizations working under the regional haze rule.

Soon after the 1999 regional rule was finalized, several parties filed petitions to challenge EPA regarding the determination of the best available retrofit technology (BART) requirements. In 2002, the Court of Appeals for the District of Columbia Circuit ruled that EPA's approach to analyze visibility impacts from multiple sources rather than on a source-by-source basis was not consistent with the CAA.[24] As a result, in April 2004, EPA refined its regional haze rule by requiring that BART apply to facilities built between 1962 and 1977 that have the potential to emit more than 250 tons a year of visibility-impairing pollutants (NOx, SO_2, and certain VOCs). These facilities fall into 26 categories, including utility and industrial boilers, and large industrial plants such as pulp mills, refineries and smelters – many of which have not been subject to federal pollution control requirements for these pollutants. With the 2004 Amendments to the regional haze rules, states are required to develop visibility SIPs by January 2008.

2.4. Emissions Controls

The U.S. has also adopted specific emissions controls on PM from a variety of sources, including stationary and mobile sources. In addition to the specific efforts aimed at PM, a variety of emissions controls have been introduced on sources of emissions that contribute to PM formation. These efforts have been focused on reducing SO_2 and NO_x emissions from a variety of emissions sources. These specific approaches are discussed in more detail in case studies 1 and 3. Provided below are details on two recent emissions controls on mobile sources.

2.4.1. Heavy-Duty Vehicles

Heavy-duty vehicles have been found to be an increasing contributor to emissions of particulate matter of up to 10 micrometers as emissions from light-duty vehicles have declined. As a result, EPA began regulating heavy-duty vehicle emissions in 1980 and updated these on several occasions. More recently, EPA adopted new regulations for"heavy-duty" vehicles which includes engine emissions standards and fuel requirements in early 2001. Under this rule, model year 2007 heavy-duty diesel engines will be required to meet engine emissions standards for PM, NO_x, and non-methane hydrocarbons of 0.01, of 0.20, and of 0.14 grams per brake-horsepower-hour (g/bhp-hr), respectively. Gasoline engines were required to meet these standards with a phase-in of 50 percent compliance from 2007 to 2009 and 100 percent in 2009. In addition, refiners will be required to produce diesel fuel with a sulphur content of 15 parts per million (ppm) beginning June 1, 2006.

2.4.2. Non road Diesels

In May 2004, EPA adopted the "non road" diesel engine rule which integrated emissions controls from engines with fuels. The engine standards apply to most diesel engines used in construction, agriculture, industrial, and airport equipment. For the non road engine standard the specific emissions level and the first year of application varies by engine type (see Table 1).

Table 1: New Non road Engine Emissions standards, grams per horsepower-hour (g/hp-hr)

Rated Power	First Year that Standards Apply	PM	NO_x
hp < 25	2008	0.30	-
25 ≤ hp < 75	2013	0.02	3.5*
75 ≤ hp < 175	2012-2013	0.01	0.30

[24] *American Corn Growers et al. v. EPA*, 291 F. 3d 1 [D.C. Cir 2002]

175 ≤ hp < 750	2011-2013	0.01	0.30
hp ≥ 750	2011-2014	0.075	2.6/0.50†
	2015	0.02/0.03**	0.50††

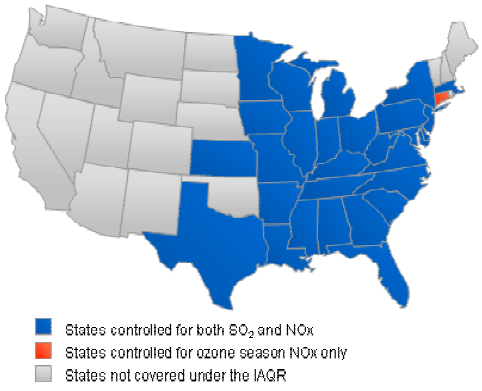
* The 3.5 g/hp-hr standard includes both NOx and nonmethane hydrocarbons.
† The 0.50 g/hp-hr standard applies to gensets over 1200 hp.
** The 0.02 g/hp-hr standard applies to gensets; the 0.03 g/hp-hr standard applies to other engines.
†† Applies to all gensets only.

Fuel suppliers will be required to supply diesel fuel to these equipment types with a decreasing quantity of sulphur. Starting in 2007, fuel sulphur levels in non road diesel will be lowered to 500 ppm from the current estimated level of 3,000 ppm. Fuel standards for sulphur will be further reduced to 15 ppm starting in 2010 for fuel supplied to non road engines and starting in 2012 for locomotive and marine diesel fuel.

At the same time, EPA announced its intent to propose new engine emissions standards for locomotive and marine diesel engines.[25]

2.4.3. Clean Air Interstate Rule

A rule recently proposed by EPA, the Clean Air Interstate Rule (e.g., "Transport Rule"), seeks to reduce interstate transport of fine particulate matter to help meet the fine particle ($PM_{2.5}$) national ambient air quality standards.[26] This proposed rule does not seek to reduce direct emissions of PM2.5. Rather, it seeks to control emissions of NO_x and SO_2, main precursors of fine particle pollution. Under the proposed rule, 29 states and the District of Columbia (see figure 5) [27] would be given SO_2 and NO_x emissions budgets in two phases (2010 and 2015) that were determined based on pro-rata reductions of historical emissions allocations for power plants in each state. Each state would be required to revise its state implementation plan to include control measures to meet the statewide emission reduction requirements implied by the emission budgets. States would have discretion in how they meet their emissions budgets, including a choice of which sources to regulate and whether or not to use emissions trading. However, to take advantage of some of the most cost-effective emissions trading options through an inter-state cap-and-trade program, states would need to adopt EPA's model rule, which limits participation to electric generating units.



[25] For more information, see: www.epa.gov/otaq/regs/nonroad/anprm.pdf
[26] The program is also designed to help states achieve the 8-hour ozone standard.
[27] The state of Connecticut was found to contribute to downwind ozone pollution but not to fine particle pollution, and therefore is only required to limit seasonal NOx emissions. If Connecticut opts into the annual trading program, there would be 29 states in total, and the cap levels described above would be adjusted to reflect Connecticut's capped emissions.

Figure 5: States Covered by the Proposed Clean Air Interstate Rule

Overall, this rule would reduce NO_x emissions in the region to 1.4 million tonnes in 2010 and 1.2 million tonnes in 2015, approximately 65 percent below current levels. The program would also simultaneously reduce SO_2 emissions in the region. SO_2 emissions would be reduced by 3.3 million tonnes in 2010—approximately 40 percent below current levels—and an additional 1.8 million tonnes when the rule is fully implemented—approximately 70 percent below current levels.[28] The control levels were established based on what was deemed to be highly cost-effective. According to the proposed rule, the SO_2 emissions limits correspond to a 65 percent reduction from the affected states' Title IV allowances in 2015 (and a 50 percent reduction from the affected states' Title IV allowances in 2010). (Title IV allowances were distributed based on 1985 to 1987 data.) Similarly, the NO_x emission limits correspond to the sum of the affected states' historic heat input in 1999 through

As in the case of the NOx SIP Call, the design of the emissions trading program under the proposed CAIR was limited by the Clean Air Act, which gives states authority to develop plans to attain the NAAQS. The streamlined national emissions trading program under Title IV of the Clean Air Act cannot easily be replicated to meet other air quality goals. Discussions are currently underway within EPA's Clean Air Act Advisory Committee on ways to provide more federal authority to regulate sources to help states to attain the NAAQS.

3. ASSESSMENT OF THE EFFECTIVENESS

To consider how effective the measures have been to address PM, we consider the environmental effectiveness, costs, and compliance and enforcement.

3.1. Environmental Effectiveness

3.1.1. Emissions

Between 1990 and 2001, total US PM_{10} emissions have declined from 25.192 to 2.1867 ktonnes—a decline of 13 percent. Of these, emissions from energy sources have increased by 125 percent and traffic emissions have decreased by over 25 percent. Miscellaneous area emissions, such as agricultural crops, forest wildfires, roads, and construction, have declined since 1990 by 15 percent but still remain the dominate source of PM_{10} emissions (see figure 6).

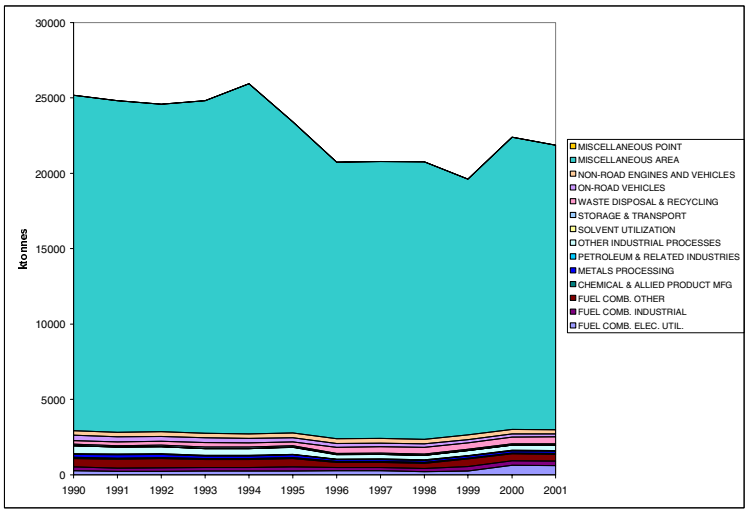


Figure 6 PM_{10} Emissions by Source

[28] More information on the rule is available at: www.epa.gov/air/interstateairquality/

Efforts in reducing PM_{10} emissions from miscellaneous area sources have achieved significant success, in percent reduction terms, compared to that of other sources. However, since these sources significantly dominate PM_{10} emissions, greater reduction from these sources are needed than from the more traditional emissions sources (e.g., stationary and mobile sources). Of miscellaneous area source emissions of PM_{10}, limited progress has been made in reducing emissions from agricultural crops and paved roads. Between 1990 and 2001, emissions from agricultural crops declined by 6 percent and emissions from paved roads increased by 28 percent. Compare this with reductions achieved from other dominate sources, such as unpaved roads—a 20 percent reduction—and construction—a decrease of 53 percent.

Emissions of $PM_{2.5}$ have witnessed a similar trend of declining emissions between 1990 and 2001. Over this period, total $PM_{2.5}$ emissions have declined from 6.859 to 6.695 ktonnes—a decrease of over 2 percent (see figure 7).

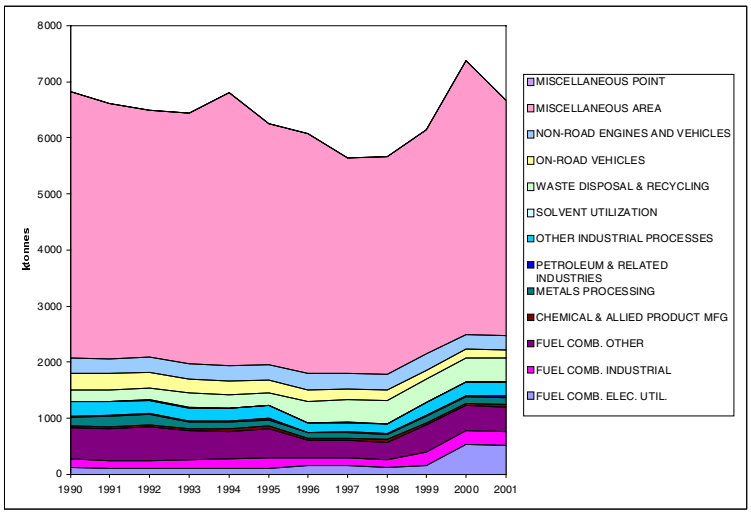


Figure 7 $PM_{2.5}$ Emissions by Source

Progress in reducing emissions has varied by emissions source. Emissions from energy sources have increased by 368 percent, while traffic emissions have declined by almost 28 percent (see figure 8). Similar to PM_{10}, progress in reducing $PM_{2.5}$ emissions from miscellaneous area sources has achieved limited success—a 12 percent reduction—and these remain a dominant source of emissions.

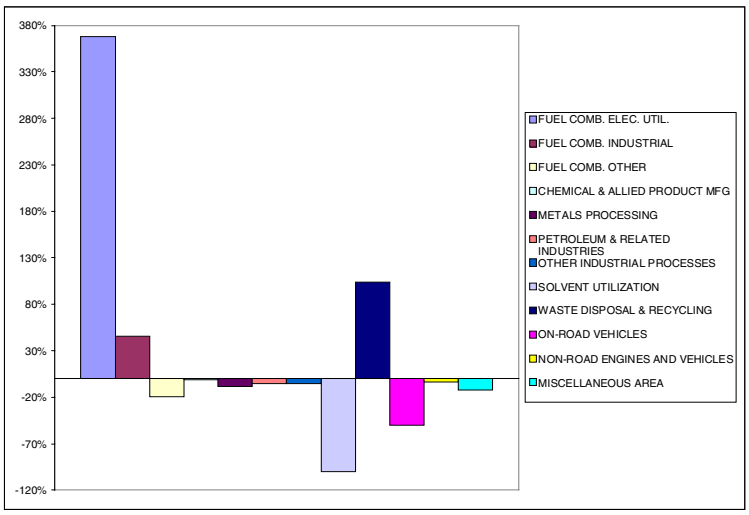
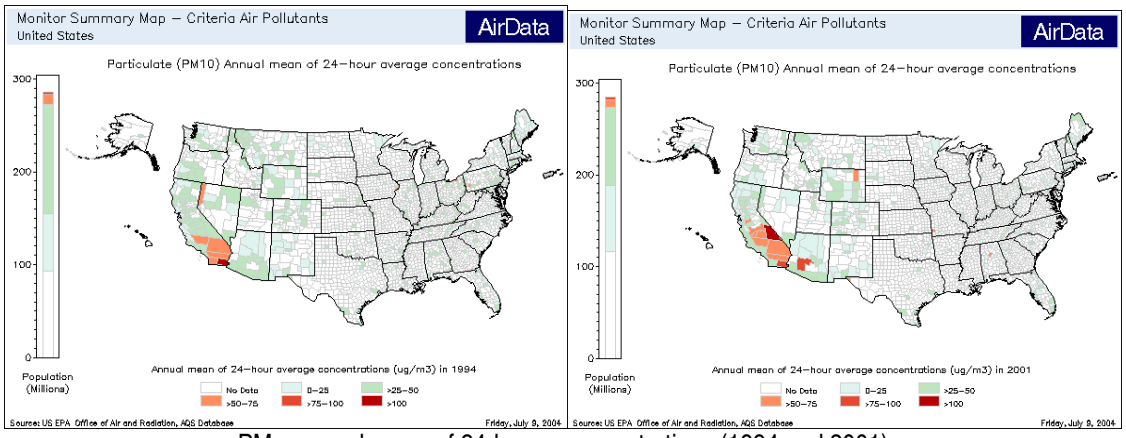


Figure 8 Percent Change in $PM_{2.5}$ Emissions by Source, 1990-2001

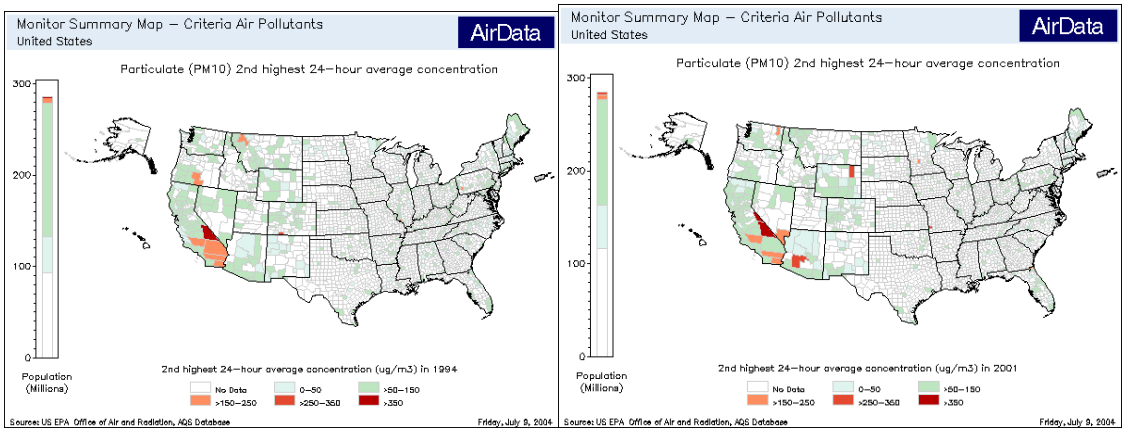
Since a number of efforts to control PM emissions, in particular for $PM_{2.5}$, have yet to take effect, it is also important to understand the expected impacts of these programs. According to EPA estimates, the proposed new engine and fuel standards for heavy-duty vehicles will reduce PM emissions by 98.883 tons by 2030 when the current fleet is fully replaced with the new engines (EPA, 2000b). Similarly, EPA estimates that the non-road engine and fuel requirement will lead to a reduction of $PM_{2.5}$ emissions of 86.157 tons in 2020 and 128.889 tons in 2020 (EPA, 2004f).

3.1.2. Impacts

These changes in emissions have led to concurrent changes in PM concentrations within the US. Figure 9 below show the level of PM_{10} concentration in the US in 1994—the first year for which data is available—and 2001.



PM_{10} annual mean of 24-hr avg concentrations (1994 and 2001)

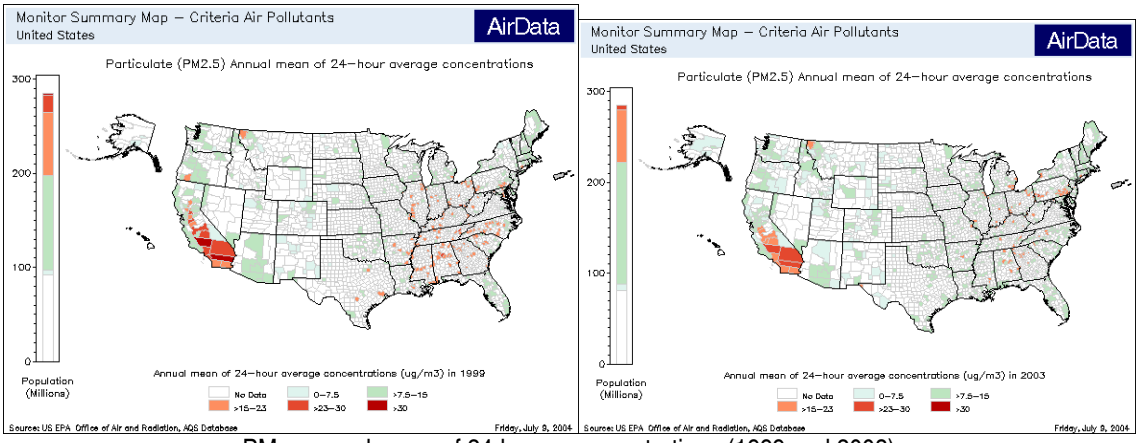


PM_{10} 2nd highest (98th percentile) 24-hr avg concentrations (1994 and 2001)

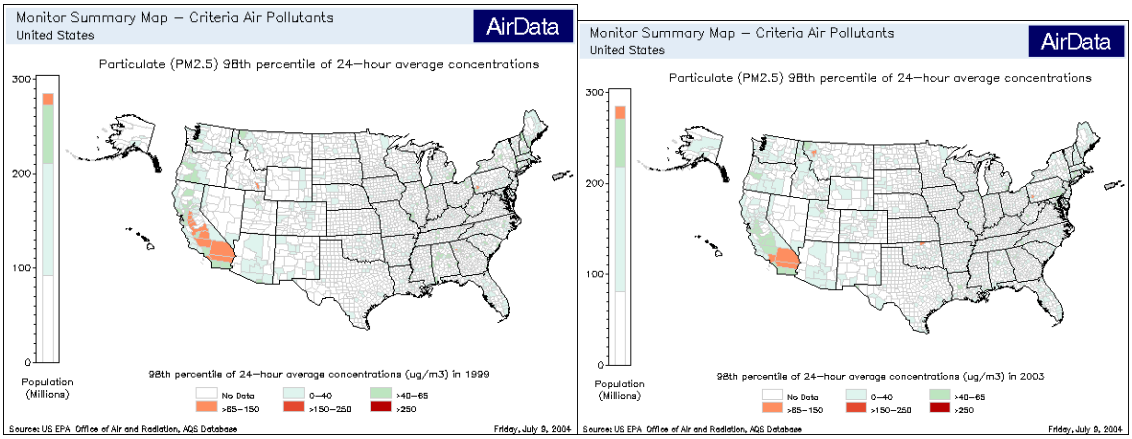
Figure 9 PM_{10} Concentration Levels (EPA, 2004b).

As can be seen, the annual mean concentrations have decreased in several areas, while the concentration has increased in others, notably in south-eastern California.

Since efforts to date have not been focused on $PM_{2.5}$, there is less information available on the progress on $PM_{2.5}$ concentration levels. Figure 10 below shows $PM_{2.5}$ concentration levels in 1999—the first year for which data is available—compared to 2003.



$PM_{2.5}$ annual mean of 24-hr avg concentrations (1999 and 2003)



$PM_{2.5}$ 2nd highest (98th percentile) 24-hr avg concentrations (1999 and 2003)

Figure 10 $PM_{2.5}$ Concentration Levels (EPA, 2004b)

Based upon this information, it is possible to discern a slight decline in $PM_{2.5}$ concentrations—both for annual mean and 98th percentile—in several areas. However, as data collection and longer time series are developed it will be possible to ascertain more concrete trends.

3.2. Costs

Since a variety of the efforts to address $PM_{2.5}$ have yet to be fully implemented, no *ex-ante* assessments are available. However, a limited number of *ex-post* analyses are available on the costs and effectiveness of specific new efforts.

3.2.1. Cost-effectiveness

EPA estimates that the heavy-duty engine and highway diesel fuel standard will increase engine costs on average $1.200 to 1.900 per vehicle and fuel costs by 1.2 to 1.3 cents per litre (EPA, 2000b). The estimated costs of the new non road engine emissions standards will vary by equipment, but for most categories will be between 1-3 percent of the total purchase price (EPA, 2004f). Table 2 shows EPA's estimates of the cost-effectiveness of the heavy-duty vehicle and non road diesel rules.[29]

[29] The values presented are the near-term cost-effectiveness. In addition, EPA estimated long-term cost-effectiveness once the cost of equipment has been mostly paid and only variable costs remain.

Table 2: Cost-Effectiveness of Heavy-Duty Vehicle and Non-road Rules, dollars per metric tonne

	NO_x + NMHC	PM	SO_x
Heavy-Duty Vehicle Rule	$2.342	$15.694	
Non-road Diesel Rule	$1.214-1.279	$12.346-13.007	$683-761

Sources: Heavy-duty vehicle rule (EPA, 2000c). Non-road diesel rule (EPA, 2004f)

3.2.2. Costs and Benefits

EPA has estimated that the non-road rule (which includes fuel requirements in addition to engine standards) will provide health benefits of $80 billion annually once essentially all older engines are replaced (EPA, 2004f). Overall costs for engine and fuel requirements are estimated at approximately $2 billion annually, yielding a cost-benefit ratio of approximately 40-to-1 (EPA, 2004f)

3.3. Compliance and Enforcement

Section 188(b)(2) of the CAA requires EPA to determine whether such moderate areas have attained the NAAQS or not within six months of the attainment date. In the event an area does not attain the NAAQS by the attainment date, section 188(d) allows States to request and EPA to approve attainment date extensions if certain criteria are met. Table 3 provides details on the progress of PM_{10} attainment.

Table 3: Number of PM_{10} No attainment Areas as of May 17, 2004 (NRC, 2004; EPA 2004d)

Classification	1992	2004	Change
Serious	8	8	0%
Moderate	78	51	35%
Total	*86*	*59*	*31%*

Since NAAQs for $PM_{2.5}$ and controls in response to recent regulations, such as the regional haze rule and heavy-duty and non-road vehicle standards, have yet to be implemented, no compliance can be calculated.