A summary of work carried out on the 'Emission factors & Cost Curves' project during 1998-2001

A report produced for the Department for Environment, Food and Rural Affairs; the National Assembly of Wales; the Scottish Executive; and the Department of Environment in Northern Ireland

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Executive Summary

This report has been prepared under the DEFRA research programme 'Emission Factors and Cost Curves for Air Pollutants' (reference EPG 1/3/134). This programme includes research aimed at improving emission factors and other data used in UK emission inventories, in particular the National Atmospheric Emissions Inventory (NAEI), and research to quantify the cost and effectiveness of control measures on emissions of air pollutants. To deliver these requirements, the programme was split into three work areas: emission factor development, inventory studies and cost curve work.

The emission factor development work has resulted in many significant changes to the NAEI and has improved the completeness and reliability of the NAEI. The UK total emissions for almost all pollutants have changed as a result of the work carried out, the changes being most significant for some heavy metals (arsenic, cadmium, chromium, copper, mercury, and zinc), polycyclic aromatic hydrocarbons (benzo[b]fluoranthene, benzo[k]fluoranthene, indeno[1,2,3-cd]pyrene, and naphthalene), and dioxins. In these cases, the change in the emission estimate for 1997 made in the NAEI changed by more than 10% between the 1997 and the 2000 versions of the NAEI. A considerable amount of revision and improvement of the estimates for many other pollutants has also occurred (e.g. volatile organic compounds), although this has resulted in changes in the UK total emission of less than 10%. Following the research, an assessment of the current state of the NAEI was made and recommendations were made for priority areas for further research. However, we would also recommend the introduction of a more transparent and systematic method for evaluating options for emission factor development which would be based on a detailed analysis of inventory uncertainty and would also consider factors such as what level of uncertainty was acceptable, the cost of research, and the likelihood of improvements resulting from that research.

The inventory studies have resulted in improvements to the volatile organic compound (VOC) speciation module of the NAEI which is now considered reasonably robust and adequate for many modelling purposes. Further relatively minor improvements to the VOC speciation module are possible using a fairly limited programme of further research. The mapping of VOC emissions has also been much improved as a result of this programme of research, although we recommend that further work should be carried out to improve the mapping of some sources, emissions from which are currently distributed using 'surrogate statistics' such as population. In addition, the mapping for those sources which are subject to emission controls should be reviewed periodically so that any reductions in emissions from these sources can be accurately reflected in the NAEI maps. Finally, research has enabled the development of a VOC temporal variation module within the NAEI, allowing diurnal, weekly, and seasonal variations in VOC emissions to be modelled. We do not recommend any further development of this module at present.

Cost curves have been developed for heavy metals, dioxins, polycyclic aromatic hydrocarbons, benzene and 1,3-butadiene. An updated cost curve for volatile organic compounds has also been generated as part of the research. The cost curves for benzene, 1,3-butadiene and VOC are available in spreadsheet format while the cost curves for heavy metals, dioxins and polycyclic aromatic hydrocarbons are available in a database ('the cost curve tool'). All of the cost curves are subject to a number of sources of uncertainty and further work is recommended, both to

better quantify these uncertainties and to gather data in order to reduce the uncertainty. There is a need to take account of the impact of measures introduced to deal with other environmental issues (such as climate change) and more data are required relating to the costs and effectiveness of control options. We also recommend that existing cost-effectiveness data for other pollutants be added to the cost curve tool, including that for benzene, 1,3-butadiene, NMVOC, SO_2, NO_x and non-agricultural sources of NH_3. Efficiencies of abatement options included in the cost curve tool towards other pollutants such as carbon monoxide could also be included relatively easily. We also recommend that the cost curve tool be more closely linked to the NAEI database which would allow more rapid updating of cost curves as the NAEI develops. Finally we recommend that options be investigated for including benefits in the cost curve tool. As an example, the costs of abating emissions of pollutants could be compared with benefits such as reductions in exposure by combining the existing cost curve tool with air quality modelling. With further development it might then be possible to apply dose-response functions to show the environmental damage that can be linked to each pollutant. If these impacts can be monetised or compared quantifiably in some other way, then this would give a method for comparing the costs and benefits of abatement options across all pollutants in a transparent and systematic way.

Contents

1 Introduction

This report has been prepared under the DEFRA research programme 'Emission Factors and Cost Curves for Air Pollutants' (reference EPG 1/3/134). The aims of the research programme were:

- To reduce the uncertainty in emission factors used in the UK's National Atmospheric Emissions Inventory (NAEI) and local inventories - to be accomplished through a combination of source measurement and the collection, assessment and harmonisation of emissions data and related information.

- To characterise and quantify the impact of control measures on emissions and the resulting cost in support of DETR (AEQ) development, implementation and monitoring of domestic and international air pollution policy.

The technical work programme required to meet these aims fell into three areas of work, the first area being significantly the largest part (about 60% of total budget):

- Emission factor development
- Inventory studies
- Development of cost curves

A description of the objectives in each work area is given below.

1.1 TASK AREA 1: EMISSION FACTOR DEVELOPMENT

1. Assess the adequacy of emission factors used in the UK NAEI in relation to:
   photochemical oxidant precursors and acid gases (except for NH_3),
   toxic metals,
   persistent organic compounds;

   and, for local inventories:
   benzene and 1,3-butadiene.

   Develop a priority list of sources requiring improved characterisation, giving attention to assessing comparability between estimates for processes covered by Parts A & B of the EP Act 1990.

2. Develop emission factors for poorly characterised sources, identified in 1 above, using measurements where appropriate.

3. Provide improved emission factors for VOCs, acid gases, persistent organic pollutants, and metals to the UK NAEI contractor, LRC emission factor database and the UNECE Emission Inventory Guidebook.

1.2 TASK AREA 2: INVENTORY STUDIES

1. Improve characterisation and quantification of VOC sources by providing improved, speciated, VOC emission factors for significant areas of uncertainty.

2. Provide data to further develop spatially resolved VOC inventories within the UK. Develop the spatial disaggregation of the VOC inventory, cross checking with local inventories. Bring together the spatial and speciated inventories to map UK VOC emissions in terms of photochemical oxidant creation potential (POCP) weighted emissions per 1 x 1 km grid square;

3. Develop a preliminary assessment of short term temporal variations in the VOC inventory in order to facilitate improved ozone modelling;

1.3 TASK AREA 3: IMPACT OF CONTROL MEASURES

1. Collate and evaluate data on the cost effectiveness of current and anticipated domestic or international control measures.

2. Develop and refine UK specific cost curves for PM_{10}, heavy metals, PAH, dioxins and furans, benzene and 1,3-butadiene.

3. If necessary, provide data/analysis to the Task Force on Integrated Assessment Modelling.

Sections 2, 3 and 4 of this report, describe how the objectives have been achieved for each task area, give brief details of the findings, conclusions and recommendations, and indicate where full results of the work may be found.

2 Emission Factor Development

The objectives of this, the largest, task area were: to assess the need for improved emission factors, identifying priority areas for research; to carry out the research necessary to generate the improved emission factors, and to disseminate the results to the NAEI contractor and other interested parties. These three objectives are described in the Sections 2.1 to 2.3. A final review of the current state of emission factors is given in Section 2.4 and recommendations for further research is given in Section 2.5.

2.1 ASSESSMENT OF EMISSION FACTORS

At the start of the programme, a review of the NAEI was made, involving personnel from both the Project team, and those responsible for compiling the NAEI. As a result of this review, a list of recommendations for research priorities was published in June 1999 (Passant & Wenborn, 1999). Some minor modifications to the review were made during the following year in the light of changing priorities and a revised report was published (Passant & Wenborn, 2000).

On the basis of these reviews, a series of research objectives were agreed with DEFRA. These can be summarised as follows:

- generation of emission factors for emissions of particulate matter, dioxins, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, polychlorinated naphthalenes and heavy metals for domestic and small-scale industrial combustion of coal;
- generation of emission factors for emissions of particulate matter, dioxins, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, polychlorinated naphthalenes for domestic and small-scale industrial combustion of wood;
- review of emission factors and emissions data for emissions of particulate matter and heavy metals from industrial processes in the ferrous, non-ferrous, mineral and chemical industries;
- development of species profiles for mercury, chromium and nickel emissions;
- development of species profiles for emissions of polychlorinated biphenyls;
- revision of emission factors for the following sources of volatile organic compound emissions – petrol distribution, film coating, paper coating, textile coating, leather coating, seed oil extraction, flexible packaging printing, publication gravure printing, tyre manufacture, manufacture of other rubber goods, wood preservation, sugar production, non-aerosol consumer products, bread baking, chemicals manufacture;
- estimation of quantities of waste burnt on small scale fires, including the burning of waste wood;
- development of emission factors for the following sources of emissions of polycyclic aromatic hydrocarbons – off-road vehicles, and manufacture & use of tar and bitumen;
- to generally improve the methodologies used for the estimation of emissions of toxic organic pollutants, heavy metals, particulate matter and volatile organic compounds by maintaining existing contacts with industrial representatives, and by identifying further contacts who could provide additional information.

Significant progress was made in all of these areas, leading to numerous changes and improvements to the NAEI. The improvements have included both the inclusion of sources which were previously omitted from the NAEI and the improvement of emission estimates for sources which were previously included. The details of this research are given in Section 2.2.

2.2 EMISSION FACTOR RESEARCH

2.2.1 Domestic combustion of coal and wood

Domestic combustion of solid fuels is a major source of particulate matter, metals and persistent organic pollutants(POPs). However, emission factors for POPs in particular were very uncertain. Therefore, CPL Ltd were subcontracted to carry out measurements of emissions from domestic style combustion devices at their premises during 2000. Emission factors for the following determinands were measured for both coal and wood:

- Polychlorinated dibenzo-p-dioxins (PCDD)
- Polychlorinated dibenzofurans (PCDF)
- Polychlorinated biphenyls (PCB)
- Polycyclic aromatic hydrocarbons (PAH)
- Total particulate matter (TPM), PM_{10} , $PM_{2.5}$)
- Carbon monoxide
- Benzene

In the case of the coal-fired boiler, emission factors for metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, and zinc) were also determined.

The measured emission factors were subject to significant uncertainties in, for example, the firing cycle of a 'typical' combustion device. But, following a comparison of these factors with those already in use in the inventory, it was recommended that, in most cases, the measured factors were an improvement on existing NAEI data and should be used. As a result, the NAEI emission factors shown below were replaced. In addition, emission factors for PCN were determined which will be used in the 2000 NAEI.

Domestic wood combustion	Domestic coal combustion
Metals (Cd, Cu, Hg, Pb, Zn)	Metals (Cr, As, Cd, Cu, Hg, Ni, Pb, Se, V, Zn)
PM_{10}	
Dioxins	Dioxins
PAHs	PAHs
	PCB

Further measurements would be beneficial, providing further data which, by increasing the sample population would lead to a better understanding of the uncertainty distribution for emission factors and thereby allow emission factors for dioxins, polycyclic aromatic hydrocarbons and other toxic organic micro-pollutants in particular to be determined with more confidence. Full details of the work are available DEFRA's Air Quality Archive at http://www.aeat.co.uk/ netcen/airqual.

2.2.2 Small-scale industrial combustion

As with domestic combustion of solid fuels, the combustion of wood and coal in small-scale industrial appliances is an important source of particulate matter, metals and persistent organic pollutants(POPs). However, emission factors for POPs in particular were very uncertain. Therefore, measurements of emissions from a small, wood-burning furnace operated at a furniture factory, and a small coal fired boiler, located at a school were carried out during 2000. The findings were published in early 2001 (Thistlethwaite, 2001a & Thistlethwaite, 2001b). Emission factors for the following determinands were measured in both cases:

- Polychlorinated dibenzo-p-dioxins (PCDD)
- Polychlorinated dibenzofurans (PCDF)
- Polychlorinated biphenyls (PCB)
- Polycyclic aromatic hydrocarbons (PAH)
- Total particulate matter (TPM), PM_{10} , $PM_{2.5}$)
- Carbon monoxide

In the case of the coal-fired boiler, emission factors for benzene and metals (antimony, arsenic, cadmium, chromium, copper, lead, mercury, manganese, nickel, selenium, tellurium, tin, vanadium, and zinc) were also determined.

The measured emission factors were subject to significant uncertainties in, for example, the firing cycle of a 'typical' combustion device. But, following a comparison of these factors with those already in use in the inventory, it was recommended that, in most cases, the measured factors were an improvement on existing NAEI data and should be used. As a result, the NAEI emission factors shown below were changed. In addition, emission factors for PCN were determined which will be used in the 2000 NAEI.

Wood combustion	Coal combustion
PM_{10}	Metals (Cr, As, Cd, Cu, Hg,
Dioxins	Ni, Pb, Se, V, Zn)
PAHs	Dioxins
	PAHs
	PCB

Further measurements would be beneficial, to increase the sampled population, providing further data on the dispersion of uncertainty which would allow emission factors for dioxins, polycyclic aromatic hydrocarbons and other toxic organic micro-pollutants in particular to be estimated with semi-quantitative uncertainty and hence with more confidence.

The full reports are available at:
http://www.aeat.co.uk/netcen/airqual/reports/emfact/AEAT0518issue1_v2.pdf and;
http://www.aeat.co.uk/netcen/airqual/reports/emfact/AEAT0517issue1_v2.pdf

2.2.3 Heavy metals and particulate matter from industrial processes

Industrial processes are important sources of heavy metals and particulate matter. Emission factors are available in the literature but emissions are very dependant upon the technology in use and the presence or otherwise of abatement. As a result, there was a need to review the available data on emission factors and emissions data for UK processes and make recommendations for appropriate factors for use in the NAEI. The review was carried out over the period 1999 to 2001. The following sectors of industry were covered:

- Coke ovens
- Sinter production
- Blast furnaces
- Basic oxygen furnaces
- Electric arc furnaces
- Iron and steel foundries
- Primary aluminium
- Secondary aluminium
- Primary lead/zinc
- Secondary lead
- Secondary copper
- Cement production
- Lime production
- Glass
- Bricks and ceramics
- Chromium chemicals
- Alkyl lead manufacture
- Chloralkali process
- Miscellaneous chemical & non-ferrous metal processes

A preliminary report was produced in 2000 (Passant, Peirce, Rudd & Scott, 2000), reviewed the available data for particulate matter emissions only. Following extensive consultation this was used as a basis for a greatly enlarged review of data for both heavy metals and particulate matter. This is currently being published (Passant, Peirce, Rudd, Scott & Watterson, 2001). The report also covers the speciation of emissions of mercury, nickel and chromium (see Section 2.2.4) and is available on DEFRA's Air Quality Archive at http://www.aeat.co.uk/ netcen/airqual.

The main findings of this review were that the NAEI should be updated in a large number of areas, and new emission factors were recommended. The work has led to a better level of detail in the NAEI for emissions of particulate matter and heavy metal emissions and more reliable emission estimates for many of the sectors listed above. Some further work is recommended, particularly with regard to estimation of fugitive emissions of particulate matter from metals and minerals processes, although other sources of particulate matter and heavy metals such as the combustion of fuels are a higher priority for further research. At UN ECE TFEIP level there is some concern that metal emissions are underestimated either because of the omission of sources from inventories, as a result of the underestimation of fugitive emissions, or as the result of resuspension of previously deposited material.

2.2.4 Speciation of mercury, chromium and nickel

Different compounds of mercury, chromium and nickel have widely varying toxicities. Therefore it is important that the NAEI is able to break national emissions of these metals down by species. To facilitate this, available data were reviewed as part of the review of heavy metal and particulate matter emission factors. Despite a paucity of measurement data, species profiles were produced for all major sources, with the recommendation that these be used in the NAEI. It was also recommended that further research, including source measurement is treated as a priority in any future programme of emission factor research. Results are available on DEFRA's Air Quality Archive at http://www.aeat.co.uk/ netcen/airqual.

2.2.5 Speciation of PCB emissions

Different PCB congeners exhibit widely varying levels of toxicity and it is important that the NAEI is able to break national emissions down by congener. To facilitate this, a review of available data on the speciation of PCB emissions was made. Although, few data are available, nonetheless, species profiles were produced for sources which contribute over 90% of mass emissions of PCBs. A report was produced in 2001 (Conolly, 2001) and the profiles were adopted in the NAEI for the 1999 set of data. The most significant PCB congeners are those that exhibit varying degrees of dioxin-like toxicity. Further measurements of speciated PCB emissions from combustion sources and desk-based research to gather data on the chemical composition of PCBs used in capacitors and transformers would improve the speciation of PCB emissions. In addition, some comparative modelling between observed ambient levels of PCBs and assumed emissions of individual PCB species might help to clarify whether both estimates of total emissions of PCBs and derived species profiles are reliable. The research report is available at
http://www.aeat.co.uk/netcen/airqual/reports/emfact/aeat_r_env_001_Issue1_v2.pdf

2.2.6 Development of VOC emission factors

The VOC inventory is subject to significant uncertainty due to the increasing adoption of emission control strategies by industrial emitters, which make historical emission factors unreliable. Research is required to determine the impact of controls and to develop up-to-date emission factors and emission estimates. Improvements in emission factors were required for a large number of sources including petrol distribution, coating of metal packaging, coil coating, film coating, paper coating, textile coating, leather coating, seed oil extraction, flexible packaging printing, publication gravure printing, print chemicals, pressure sensitive tapes manufacture, tyre manufacture, manufacture of other rubber goods, wood preservation, sugar production, non-aerosol consumer products, bread baking, chemicals manufacture. Research has been carried out over the period 1988 – 2001 to develop better data for these sources.

Better estimates were made through consultation with trade associations, regulators, industry and other researchers. As a result, many major improvements have been made, and we believe that the NMVOC inventory is significantly more robust than at the start of this research programme. In particular, the work has allowed the NAEI to indicate the significant reductions in NMVOC emissions which have occurred as a result of legislation such as the Environmental Protection Act. Further research will, however, be necessary in order to quantify and track trends resulting from the continuing and increasing use of emission reduction strategies by industry.

Details of much of the work carried out have been included in Coleman *et al*, 2001 (available at http://www.aeat.co.uk/netcen/airqual/reports/emfact/AEAT_ENV_0575_v2.pdf) and additional details not published elsewhere are given in Appendix 1.

2.2.7 Development of PAH emission factors

The review of the NAEI (Passant & Wenborn, 2000) carried out at the start of the research programme had identified a couple of omissions from the inventories for polycyclic aromatic hydrocarbons (PAHs). Research was carried out to fill these gaps, and involved:

- derivation of emission factors and emissions for off-road vehicles using analogous on-road vehicle data;
- derivation of estimates of PAH emissions and emission factors from the manufacture and use of tar and bitumen.

Details of these work elements have been given in Coleman *et al*, 2001. The work allowed emission estimates for these sources to be included in the NAEI for the first time. The research indicated that these were minor sources of PAHs and further development of the estimates is probably not warranted at present.

2.2.8 Small-scale waste burning

The small-scale burning of waste (e.g. on domestic grates, bonfires, small fires on construction and industrial sites) is a source of emissions of persistent organic pollutants, however no reliable activity data are available from official sources and no estimates have been made in the NAEI until now. Estimates of waste arisings and quantities burnt have therefore been made as part of this programme of work allowing this source to be included in the 2000 NAEI. Details of the findings are given in Appendix 1.

2.2.9 General data collection

As well as carrying out detailed studies, the programme of research has included a proactive element of using any contacts with other researchers and trade associations to gather information and data which has often led to improvements in emission factors and therefore the NAEI. As an indication of the importance of this activity, Appendix 2 includes a list of all organisations who were able to provide some help in improving emission estimates.

2.2.10 Impact of emission factor studies

The emission factor research carried out under this research programme has had two impacts: emission factors for sources previously omitted from the inventory have been generated and some existing emission factors have been revised. Table 1 shows the change in the UK total emissions for each pollutant as a result of the addition of new factors and revisions to existing factors between the 1997 version of the NAEI and the 2000 version of the NAEI. The Table shows clearly that, for many pollutants, the work has led to significant changes in the UK total emission. In particular, changes made to the cadmium, chromium and zinc inventories are most significant, followed by changes to the inventories for arsenic, copper, mercury, dioxins and a number of polycyclic aromatic hydrocarbons. The major changes in these inventories are shown in Table 2. Interestingly, in the case of NMVOC, whilst a considerable amount of revision and improvement of the estimates has occurred, this has resulted in only a small change in the UK total emission.

Table 1. Impact of emission factor research on the NAEI between 1997 and 2000 (emission data are for 1997)

Pollutant	Change due to addition of new factors	Change due to revisions to factors	Overall change	UK emission	Change as % of UK emission
Emissions in ktonnes					
CO	82	-	82	5320	1.5%
HCl	0.15	-	0.15	94.4	0.2%
HF	0.25	-	0.25	4.93	5.0%
NOx	0.26	-	0.26	1860	0.0%
SO_2	38	-	38	1670	2.3%
VOC	29	-80	-51	2100	2.4%
PM_{10}	15	-8.7	6.4	228	2.8%
Emissions in tonnes					
Arsenic	0.08	-9.3	-9.2	52.6	17.5%
Cadmium	0.14	-7.1	-7.0	7.82	89.2%
Chromium	27	12	39	86.2	45.2%
Copper	10	1.2	11	66.2	17.2%
Mercury	0.24	-1.8	-1.5	12.2	12.5%
Nickel	6.6	6.7	13	223	6.0%
Lead	135	-147	-12	1180	1.0%
Selenium	0.1	-3.7	-3.7	78.6	4.7%
Vanadium	0.1	-12	-12	446	2.6%
Zinc	40	-290	250	655	37.5%
Acenapthene	2.5	1.0	3.5	55.6	6.3%
Acenapthylene	3.1	1.3	4.5	114	3.9%
Anthracene	0.42	0.35	0.77	62.1	1.2%
Benz[a]anthracene	0.55	0.34	0.89	19.2	4.7%
Benzo[a]pyrene	2.0	-1.8	0.21	12.8	1.6%
Benzo[b]fluoranthene	1.3	0.03	1.3	13.3	10.2%
Benzo[ghi]perylene	0.55	0.16	0.71	7.26	9.8%
Benzo[k]fluoranthene	0.67	0.02	0.69	6.27	11.0%
Chrysene	0.76	0.33	1.1	26.8	4.1%
Dibenz[ah]anthracene	0.036	0.34	0.38	6.87	5.5%
Fluoranthene	1.1	0.62	1.7	100	1.7%
Fluorene	0.57	3.1	3.7	106	3.5%
Indeno[1,2,3-cd]pyrene	0.74	0.24	0.98	7.74	12.6%
Napthalene	48	24	72	688	10.5%
Phenanthrene	4.3	1.4	5.7	229	2.5%
Pyrene	0.98	0.57	1.6	65.2	2.4%
PCBs	150	-	150	3400	4.4%
Emissions in grammes (ITEQ)					
Dioxins	50	22	72	466	15.6%

Table 2 Major changes in the NAEI estimates

Pollutant	Revision or addition
Cadmium	Revision to factors for primary lead/zinc production and electric arc furnaces
Chromium	Addition of factors for chromium chemicals and general chemicals manufacture. Revision of factor for electric arc furnaces
Copper	Addition of factors for copper alloys and semis production and chemicals manufacture Revisions to factor for secondary copper production
Arsenic	Revision of factor for domestic coal combustion
Mercury	Revision to factor for primary lead/zinc production
Zinc	Revision to factor for primary lead/zinc production and secondary lead production
Dioxins	Addition of emission factor for small-scale waste burning
Benzo[b]fluoranthene, Benzo[k]fluoranthene, Indeno[1,2,3-cd]pyrene, Naphthalene	Addition of emission factor for small-scale waste burning

2.3 DISSEMINATION OF RESULTS

Copies of research reports have been provided to the NAEI contractor and data, including emission factors and activity data have been provided in electronic form. Electronic versions of reports have also been placed on DEFRA's Air Quality Archive at http://www.aeat.co.uk/netcen/airqual. Where possible, the results of research have also been disseminated to interested groups in industry, for example, trade associations. Finally, research findings and reports have been circulated to inventory workers outside the UK, particularly the UN ECE TFEIP, with the aim both of using UK data to improve inventory quality elsewhere and also to encourage the flow of emission factor data between national inventory experts.

2.4 CURRENT ASSESSMENT OF AREAS OF UNCERTAINTY IN THE NAEI

2.4.1 Polycyclic aromatic hydrocarbons (PAH)

The emission factor research programme has provided new and improved emission factors for major sources including domestic fires and small industrial combustion processes. In addition, sources missing from earlier versions of the NAEI (off-road vehicles, and tar and bitumen processes) are now included, again following research funded under this programme. Emission estimates can also now be made for the small-scale burning of waste, following research aimed at estimating the quantities of waste burnt in this way.

The most recent published NAEI data are those for 1999, and the figures for benzo(a)pyrene are shown in Table 3.

Table 3. Emissions of benzo[a]pyrene in 1999

Source	% emission
Vehicles – petrol	20
Natural fires and open agricultural burning	18
Domestic combustion of coal and smokeless solid fuel	18
Anode baking	12
Industrial coal combustion	9
Domestic combustion of wood	7
Coke ovens	6
Vehicles – diesel	4
Sinter plants	2
Aluminium production	1
Other sources	2

The benzo[a]pyrene (B[a]P) inventory is dominated by combustion related sources, the only other significant sources being the baking and use of coal tar pitch/petroleum coke based anodes in the aluminium industry and emissions from coke production. It should be noted that comparisons of the inventory with levels of B[a]P in the atmosphere suggest that the inventory may be an underestimate.

Measurements have recently been made on domestic and small industrial combustion processes as part of this research programme (see sections 2.2.1 and 2.2.2). Nevertheless, emission factors for combustion processes continue to be based on a fairly limited set of data and further measurements might improve confidence in emission estimates. Consequently, emission factors must still be regarded as being fairly uncertain, particularly for closed domestic appliances where no measurements have been made, and further measurements of emissions from certain types of appliances are therefore recommended as a high priority.

In the case of large fuel oil fired combustion plant, current emission factors are based on measurements made of emissions from coal-fired plant and therefore are subject to considerable uncertainty. Although the quantity of fuel oil burnt in large combustion plant is relatively small, nevertheless the development of an emission factor based on measurements at a representative plant is a high priority.

Emission factors for coke ovens and anode production and use are generally based on measurements carried out by process operators. One area of uncertainty is emissions from coke ovens operated outside of the iron and steel industry, where no emission measurements are available. Previously, measurements as part of this programme have been considered, however, due to the fugitive nature of much of the emission, any measurements would be expensive and the results subject to considerable uncertainty. However, it is recommended that regulators and process operators be contacted as a high priority to check whether they hold any data which could be used to improve the inventory.

Previous work has indicated that creosote contains PAH species, however, there is considerable uncertainty over the extent of and the rate at which these species are emitted. As a high priority, measurements should be undertaken to address these issues.

Emission estimates can be made small-scale waste burning, as a result of work carried out as part of this programme which led to the generation of activity data for the first time. These estimates are, however, very uncertain due to a lack of good data on the proportion of waste arisings which are burnt. The estimates should, if the source appears to be significant, be improved by more detailed studies as a high priority.

Preliminary estimates of emissions from bitumen production and use have been made as part of this programme. Measurements of emissions from bitumen refineries would be a starting point for improvements to these estimates and should be treated as a medium priority.

Speciation of PAH emissions is generally considered to be acceptable. Nonetheless any studies which are carried out to determine PAH emission factors should collect data on species emitted. The spatial disaggregation of PAH emissions has also been improved recently, although further work to identify point sources and improve mapping of area sources should be considered a medium priority. Temporal disaggregation of emissions is less crucial and, although improvements could be made, this should be considered a low priority.

2.4.2 Dioxins and furans

The emission factor research programme has provided improved emission factors for major sources including domestic fires and small industrial combustion processes. Emission estimates can also now be made for the small-scale burning of waste, following research aimed at estimating the quantities of waste burnt in this way. Emissions data for dioxins and furans from the 1999 NAEI are shown in Table 4.

Table 4. Emissions of dioxins and furans in 1999

Source	% emission
Natural and accidental fires	20
Sinter plants	12
Industrial wood combustion	9
Non-ferrous metal production	7
Industrial oil combustion	7
Clinical waste incineration	7
Industrial coal combustion	6
Crematoria	5
Electric arc furnaces	5
Power stations	5
Other incineration	4
Other combustion	3
Domestic combustion	3
Road transport	2
Other sources	5

Dioxins are emitted only from combustion related processes apart from a few other types of source which are of minor importance. Most confidence can be had for estimates for sinter plants at integrated iron & steel works, and municipal solid waste incinerators, since most monitoring has been carried out at these sites. Elsewhere, emission estimates are generally based on a limited number of emission measurements and further measurements might increase the level of confidence in the estimates. As with PAH emissions, the high priority sources are fuel oil fired large combustion plant and closed domestic appliances.

Emissions from clinical waste incinerators are relatively uncertain and should be improved through measurements. However, we believe that measurement work carried out by operators may be available and in the public domain and, as a high priority, this should be explored before any measurement work is contemplated.

Dioxin emissions from chemical manufacturing processes and ferrous and non-ferrous metal processes are not well characterised with the exception of certain sources such as integrated steelworks. As a medium priority, desk based studies to identify potential sources of dioxin emissions should be considered.

Speciation of dioxin emissions is generally considered to be acceptable. Nonetheless any studies which are carried out to determine dioxin emission factors should collect data on species emitted.

2.4.3 Polychlorinated biphenyls

The emission factor research programme has provided improved emission factors for sources including domestic fires and small industrial combustion processes. Emission estimates can also now be made for the small-scale burning of waste, following research aimed at estimating the quantities of waste burnt in this way. The speciation of PCB emission estimates is possible now for the first time as a result of the development of species profiles for all major sources.

Emissions data for polychlorinated biphenyls (PCBs), taken from the current version of the NAEI, are shown in Table 5

Table 5. Emissions of PCB in 1999

Source	% emission
Leakage from capacitors	76
Electric arc furnaces	11
Fragmentisers	4
Sinter plants	2
Power stations	2
Leakage from transformers	2
Application of sewage sludge	1
Other combustion	1
Basic oxygen furnaces	1
Other sources	1

PCBs were historically used in electrical components and emissions from these components, either as a result of leakage during use, or as a result of evaporation during disposal of the components, dominate the inventory. In-situ formation of PCBs during combustion is a minor source in comparison.

The largest source is leakage from capacitors. Uncertainty in this estimate derives both from uncertainty as to the leakage rates, but also as to the size of the 'bank' of PCBs still available in capacitors. A similar problem affects the estimate for leakage from transformers. It is recommended that, as a medium priority, trade associations, industry and other organisations be contacted to determine what data might be available with which to improve estimates.

Improvements to other sources such as landfill sites, electric arc furnaces and fragmentisers are a low priority, especially given the difficulty in conceiving of any good method of improving emission estimates.

A preliminary speciated PCB inventory has been completed, however further development should be considered a high priority.

2.4.4 Hexachlorohexane, pentachlorophenol, & hexachlorobenzene

Research aimed at improving emission estimates for these three pollutants was not identified as a priority and has not therefore been included in the emission factor research programme.

Tables 6a, 6b and 6c give summaries of the latest emissions data for hexachlorohexane (HCH), pentachlorophenol (PCP), and hexachlorobenzene (HCB) respectively.

Table 6a. Emissions of HCH in 1999

Source	% emission
Evaporation from treated wood	66
Pesticide use	20
Wood impregnation	14

Table 6b. Emissions of PCP in 1999

Source	% emission
Evaporation from treated wood	90
Evaporation from imported wood	10
Other sources	<1

Table 6c. Emissions of HCB in 1999

Source	% emission
Pesticide use	70
Chemical industry	30
Incineration	<1

The inventories for HCH and PCP are dominated by emissions resulting from wood treatment. Pesticide use, and manufacture of chemicals dominate the HCB inventory. Estimates are very uncertain, however the figures are decreasing. Improvements could be made to the inventories, both by obtaining better activity data for pesticide use, and by improving emission factors e.g.

for pesticides or estimation methodologies e.g. release rates for treated wood. Further work on pesticides is considered a high priority and work on treated wood is considered a medium priority.

2.4.5 Particulate matter

The emission factor research programme has provided improved emission factors for sources including domestic fires and small industrial combustion processes. Emission estimates can also now be made for the small-scale burning of waste, following research aimed at estimating the quantities of waste burnt in this way. Other significant improvements have resulted from the review of emission factors for industrial processes.

Emissions data for PM_{10}, taken from the current version of the NAEI, are shown in Table 7.

Table 7. Emissions of PM_{10} in 1999

Source	% emission
Domestic combustion	20
Road transport	20
Industrial combustion	13
Quarrying	11
Power stations	10
Industrial processes	10
Agriculture	8
Other transport	6
Construction	2
Other sources	1

Combustion processes are the major source of PM_{10} emissions. Important non-combustion related sources include quarrying and agriculture.

Measurements of emission factors for small combustion processes have been included in the research described in section 2.2. Even with these new factors, emission estimates for combustion of solid fuels in the domestic and small industry sectors are still relatively uncertain due to the small sample of data on which the emission factors are based. Further measurements would improve confidence in emission estimates, but are perhaps only a medium priority.

Emission factors for combustion of natural gas are also uncertain or, in the case of power stations, completely lacking. The inclusion of an emission factor for combined-cycle gas turbines (CCGTs) used in the electricity supply industry (ESI) in the NAEI is therefore a high priority. Emission factors for domestic gas combustion have attracted some concern, because nationally this source is now almost as significant as domestic combustion of wood or coal. As a high priority therefore, the emission factor used for domestic gas combustion should therefore be reviewed in the light of literature values and recommendations made as to the need for either revisions to the NAEI or the need for measurements.

Emission estimates for quarrying remain very uncertain. These estimates are derived using the methodology published by the US Environmental Protection Agency (USEPA) in their compilation of emission factors known as AP-42. In order to use this methodology, it has been necessary to make some assumptions about the nature of UK quarrying activities. It is anticipated that a short, desk-based exercise could improve the confidence of estimates by obtaining more information on the UK quarrying industry on which to base these assumptions. However, this type of study is unlikely to significantly improve confidence and is therefore a low priority.

Emission estimates for industrial processes have been significantly improved through a study that has been completed as part of this programme, and although further development of this work is recommended, it is only a medium priority.

The time series for industrial processes is not well developed, since estimates before about the mid 1990s are generally based on emission factors. It could be improved through discussions with regulators and industry, however a fairly extensive programme of work would be necessary and might not lead to major improvements in the quality of the time series. In the absence of a specific need to obtain improved emission estimates for this earlier part of the time series, such an exercise is a low priority.

Emissions from construction are, like emissions from quarrying, subject to considerable uncertainty. The UK figure is based on the single factor for particulate matter given by the USEPA in AP-42. An adjustment has been made in order to take account of differences in meteorological conditions between the US and the UK, and 20% of the emission has been assumed to be PM_{10}. In the absence of other literature values, it is difficult to imagine that any improvements could be made to the estimates for this source without extensive measurements.

Size distributions and chemical composition data for particulate matter emissions are either uncertain or entirely lacking for most sources. Further desk-based studies are recommended to search for further data contained in the literature and also through discussions with industry, trade associations and other researchers.

2.4.6 Heavy metals

The emission factor research programme has provided improved emission factors for sources including domestic fires and small industrial combustion processes. Other significant improvements have resulted from the review of emission factors for industrial processes.

Table 8 gives a summary of the latest emissions data for heavy metals.

Table 8. Emissions of heavy metals in 1999 (figures in %)

Source	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	V	Zn
Industrial combustion	54	11	7	17	15	62	5	14	75	18
Iron and steel processes	3	17	24	23	7	8	8	1	5	49
Power stations	11	7	26	21	18	7	3	26	7	4
Glass production	9	8	5	1	1	1	9	46	4	3
Transport	0	6	1	1	0	3	60	1	5	3
Domestic combustion	17	5	6	6	7	14	3	10	4	2
Incineration	1	11	0	1	23	0	1	0	0	2
Primary lead/zinc	1	19	0	1	3	0	2	-	-	5
Chromium chemicals	-	-	27	-	-	-	-	-	-	-
Other non-ferrous metals	0	2	0	7	0	3	1	0	0	6
Other chemicals	0	6	0	7	1	1	0	0	-	3
Chlor-alkali process	-	-	-	-	17	-	-	-	-	-
Secondary copper	0	1	-	11	-	0	1	-	-	3
Secondary lead	0	4	-	0	0	-	1	1	-	0
Alkyl lead manufacture	-	-	-	-	-	-	5	-	-	-
Other sources	2	2	4	3	8	1	2	0	0	2

Heavy metal emissions occur from both combustion and non-combustion sources. Combustion is the dominant source for arsenic, lead, nickel and vanadium, while non-combustion sources dominate for cadmium, chromium, mercury, and zinc.

Emission factors are not available in the NAEI for a number of Part B processes including quarries and galvanising processes, and the available data should be assessed as a medium priority. One further potential source is the small-scale burning of waste and emission factors for this source would be required. However, we believe this source would be relatively minor and further work is a low priority.

In general, estimation of emissions from combustion processes relies either upon knowledge of the metal content of fuels, or on emissions data provided by process operators, which in turn will be based on metal content of fuels. Metal contents are uncertain in many cases, as is the partitioning of metals between collected particulate matter and released particulate matter. Therefor, a review of currently available data is recommended as a high priority action, and analysis of some fuels is recommended as a medium priority. The recently completed review of heavy metal emission factors for industrial processes has significantly improved emission estimates but more could be done – further development of these emission factors is considered a medium priority.

The above study also provided first estimates of species profiles for sources of mercury, nickel and chromium but these are very uncertain, and for many sources no data were available at all. Therefore, as a high priority, further desk based studies are recommended to gather data from the literature and from industry, trade associations and other researchers.

Some development of additional point source data and improvements to mapping of area sources is recommended, but as a medium priority.

2.4.7 Carbon monoxide

The emission factor programme has included research to identify sources of carbon monoxide from chemical processes, a source which has not been included before. The research has shown that this is not a major source of the pollutant although it is not trivial (about 0.3% of the national total).

Emissions data for carbon monoxide, taken from the current version of the NAEI, are shown in Table 9.

Table 9. Emissions of carbon monoxide in 1999

Source	% emission
Road transport	69
Off-road vehicles	9
Basic oxygen furnaces	7
Domestic combustion	5
Other combustion	3
Sinter plants	2
Chemical industry	2
Other transport	1
Other sources	3

Carbon monoxide is emitted mainly from combustion processes (especially road transport), with only about 13% of emissions from other types of source. Emission factors for combustion processes are generally considered to be reasonable, although the factors for domestic combustion would be the first choice for improvement. Further work, however, is a low priority.

2.4.8 Hydrogen chloride

Research aimed at improving emission estimates for this pollutant was not identified as a priority and has not therefore been included in the emission factor research programme.

Table 10 summarises the most recent emission estimates for hydrogen chloride.

Table 10. Emissions of hydrogen chloride in 1999

Source	% emission
Power stations	84
Industrial combustion	9
Domestic combustion	6
Other sources	0

Emissions of hydrogen chloride occur almost exclusively as a result of coal combustion. Emission factors are considered reliable and this part of the NAEI is not a priority for further development. However, it is possible that some processes may produce emissions of hydrogen chloride and so a medium priority is research to identify potential sources.

2.4.9 Sulphur dioxide

The emission factor programme has included research to identify sources of sulphur dioxide from chemical processes, sources which have not been included before. The research has shown that these are not major sources of the pollutant although they are not trivial (about 1.3% of the national total).

Emissions estimates for sulphur dioxide, taken from the current version of the NAEI, are shown in Table 11.

Table 11. Emissions of sulphur dioxide in 1999

Source	% emission
Power stations	65
Industrial combustion	20
Domestic combustion	4
Other transport	3
Road transport	1
Other sources	6

Sulphur dioxide is emitted mainly as a result of combustion of coal and fuel oil. Emission factors are based on measured fuel sulphur contents and so the inventory is generally considered to be well characterised. Some processes emit sulphur dioxide but these are generally covered by the Pollution Inventory which is considered a reasonably reliable sources of data on these emissions. Better data on sulphur contents of solid smokeless fuel (SSF) and marine fuel oil would be desirable, although it is unlikely that a reliable figure for the latter could be obtained without carrying out an in-depth study. In any case, these are a low priority for action.

2.4.10 Oxides of nitrogen

Research aimed at improving emission estimates for these three pollutants was not identified as a priority and has not therefore been included in the emission factor research programme.

Table12 gives a summary of the latest emissions data for oxides of nitrogen.

Table 12. Emissions of oxides of nitrogen in 1999.

Source	% emission
Road transport	44
Power stations	21
Industrial combustion	14
Other transport	12
Domestic combustion	4
Other sources	5

Emissions occur almost exclusively as a result of combustion. Emission factors are based on measurements or taken from the literature, and are generally regarded to be good.

2.4.11 Volatile organic compounds

The NMVOC inventory has benefited from research into emissions from industrial solvent use, domestic solvent use, petrol distribution, petroleum and gasification processes, the food & drink industry, and the chemical industry. This research has led to numerous revisions to emission factors used in the NAEI which in turn have enabled the NAEI to indicate large reductions in the estimated emissions from these processes over the period 1997 to 1999 (from 785 ktonnes to 615 ktonnes).

Emissions data for volatile organic compounds (VOC), taken from the current version of the NAEI, are shown in Table 13.

Table 13. VOC emissions in 1999

Source	% emission
Road transport	27
Industrial solvent use	17
Forests	10
Domestic solvent use	10
Oil exploration & production	9
Refining & petrol distribution	8
Food & drink industry	5
Chemical industry	4
Other transport	4
Combustion	4
Industrial processes	1
Other sources	2

Emissions of VOC occur from a wider range of sources, including road transport, solvent use, and industrial processes. The inventory has been much improved in recent years, however a number of significant issues remain. Most important of these is the difficulty in routinely updating the inventory on an annual basis due partly to the absence of suitable activity data and partly to changes in emission characteristics resulting from implementation of the Environmental Protection Act, Solvent Directive, and other legislation. As a result, the methodology used for the VOC inventory must be continually updated.

Priority areas for further development are industrial solvent use, and the food and drink industry. Estimates for large solvent-using processes are estimated based on information provided by regulators and/or process operators but, because of the likelihood of abatement systems being introduced, these estimates need to be revised on a periodic basis. The sectors involved include printing (publication gravure and flexible packaging), textile coating, paper coating, film coating, coating of metal packaging, tyre manufacture, seed oil extraction and manufacture of pressure sensitive tapes. Where possible, data should also be collected for other major printing processes and major users of solvent containing adhesives. The updating of these estimates at three yearly intervals is a high priority. Other sectors such as drum coating and leather coating are less important and might be updating at five year intervals.

Emission estimates for certain food industry processes are very uncertain. A desk-based study could be carried out with the aim of gathering more information on food industry processes.

The study could look at animal feed manufacture, oils & fats manufacturing, animal rendering, fish meal production, meat and fish cooking, manufacture of baked products other than bread, coffee roasting & decaffeination, and flavour and essence production. This study is considered a high priority.

Estimates for screen wash, solvent-based wood preservation and rubber goods manufacture have been made slightly less uncertain through discussions with industry which have suggested that the current estimation methodologies give reasonable estimates. As a medium priority, further effort should be made to gather data and encourage trade associations and industry to contribute information. As a high priority, a similar exercise is needed for other solvent using processes such as adhesives and the current NAEI category 'other solvent use'. Other sectors such as leather degreasing, print chemicals, heatset web offset, screen printing and miscellaneous printing processes could be addressed by desk based studies but should probably be considered a low priority at present.

Spatial disaggregation and speciation of NMVOC sources has been greatly improved in the past 3 years but the data used will need to be updated periodically. This is a high priority in the case of point source data and a medium priority in the case of speciation.

2.4.12 Benzene

Research aimed at improving emission estimates for these three pollutants was not identified as a priority and has not therefore been included in the emission factor research programme.

Table14 gives a summary of the latest emissions data for benzene.

Table 14. Benzene emissions in 1999.

Source	% emission
Road transport	71
Domestic combustion	10
Other transport	6
Refining & petrol distribution	5
Other combustion	4
Other industrial processes	4
Other sources	1

The inventory is dominated by combustion related sources, in particular road transport. The most important stationary source is domestic combustion of wood. The factor for wood combustion is based on a USEPA species profile which is given a data quality of D and which included test runs on an appliance fitted with a catalytic control device. This may not be particularly applicable to the UK and measurement work could be considered, although it is a low priority.

Other significant stationary sources of benzene include domestic combustion of coal and natural gas, refineries, and chemical industry processes. The emission factor for domestic coal combustion is based on a fairly extensive set of measurements and must be considered more reliable than that for natural gas, which is based on a species profile for natural gas boilers. The natural gas factor should ideally be tested by measurement but, due to the low levels of VOC from gas combustion, measurements are unlikely to be reliable enough to significantly improve the level of certainty.

The emission estimates for chemical industry processes are based on data reported in the PI. Little or no background information has yet been obtained on these sources on which to base a judgement as to the reliability of the emission estimates. Other chemical industry processes might emit benzene as well but, again, insufficient background information has been collected to date that would allow such processes to be identified. The analysis of background information on IPC processes, obtained from the Environment Agency would be a useful exercise, allowing a better evaluation of the benzene inventory. It is considered a medium priority

2.4.13 1,3-butadiene

Research aimed at improving emission estimates for these three pollutants was not identified as a priority and has not therefore been included in the emission factor research programme.

Emissions data for 1,3-butadiene, taken from the current version of the NAEI, are shown in Table 15.

Table 15. 1,3-butadiene emissions in 1999

Source	% emission
Road transport	85
Other transport	8
Chemical industry	6
Other sources	1

The inventory for 1,3-butadiene is dominated by transport-related combustion. The chemical industry is the only other significant source. As mentioned for benzene in the previous section, background information on chemical processes should be examined so that the reliability of the emission estimate can be assessed. As with the benzene inventory, such an exercise is a medium priority.

2.4.14 Ammonia

The objectives of the emission factor programme excluded any research aimed at improving emission estimates for ammonia. In the future, we recommend that development of improved emission factors for non-agricultural sources of ammonia should be included in further emission factor research programmes. The uncertainty in that part of the ammonia inventory is considered below with recommendations for priority research areas.

Table 16 gives a summary of the latest emissions data for ammonia.

Table 16. Ammonia emissions in 1999

Source	% emission
Animal wastes (agricultural)	71
Agricultural soils	9
Animal wastes (non-agricultural)	7
Road transport	6
Industrial processes	1
Combustion	1
Other sources	5

The major sources of ammonia are agricultural – animal wastes and soils. Apart from non-agricultural animals (including horses, pets, and wild animals) and road transport, the only other sources of any significance are coal and wood combustion, sewage sludge disposal, landfill sites and chemical industry processes. Emission estimates for agricultural sources are provided to the NAEI directly by DEFRA and uncertainty in this part of the inventory is not considered further.

Emissions from combustion related sources are based on a limited number of emission factors e.g. domestic wood, anthracite and SSF are based on domestic coal factor, all industrial combustion of solid fuels based on single emission factor. The UN ECE Emission Factor Guidebook and AP42 could be reviewed for suitable emission factors; if these are not available or if the factors given are very uncertain, then measurements might be recommended. Where measurements are being made for other determinands, then measurements of ammonia could be considered.

Emissions for sewage sludge spreading and sewage treatment works in particular are uncertain, and the assumptions made in order to estimate emissions have often not been verified by detailed study. A desk-based exercise to gather more data on the sewage treatment industry is therefore a high priority.

Landfill emissions are very uncertain, and the simple estimation method used in the NAEI has not been verified by measurements. Measurement of ammonia levels in landfill gas are a high priority.

Certain food industry processes and Part B processes such as fish meal processing and maggot farms emit ammonia, but few data on emissions exist. Further desk based work to collate information is a medium priority.

2.4.15 Other pollutants

Inventories are currently being developed or have recently been developed for a number of other pollutants as follows:

Polychlorinated naphthalenes (PCN)
Short-chain chlorinated paraffins (SCCP)
Calcium
Magnesium
Sodium

Potassium
Polybrominated diphenyl ethers (PBDE)
Tin
Manganese
Beryllium

Further work is required to identify good emissions data for many of these processes. This work should take the form of desk-based exercises and is a high priority in the case of SCCP and PBDE. In addition, it is recommended that measurement of PCN emission factors for large combustion plant is a high priority and that improvements in emission factors and estimation methodologies for other PCN sources and all sources of calcium, magnesium, sodium and potassium are a medium priority. Inventories for the final three pollutants listed above are being developed for inclusion for the first time in the forthcoming 2000 NAEI and are not considered further here.

2.5 PRIORITY AREAS FOR FURTHER RESEARCH

From the discussion in Section 2.4, a large number of priority areas for further development of emission factors can be drawn up. These priorities have been split into high, medium and low priorities and are listed by pollutant in Appendix 3. In summary, the priority areas cover most but not all pollutants included in the NAEI (no priority areas are identified for NOx or SO_2). Most of the high priority actions relate to ammonia, NMVOC, particulate matter, heavy metals, dioxins and furans, polycyclic aromatic hydrocarbons, pesticides, polychlorinated biphenyls and polychlorinated naphthalenes, short chain chlorinated paraffins, and polybrominated diphenyl ethers while only medium or low priority actions have been identified for hydrogen chloride, hydrogen fluoride, benzene, 1,3-butadiene, carbon monoxide and base cations. Priority actions include both the need for new emission factors based on source measurement and desk-based research.

The current list of 'qualitative' priorities has been drawn up based on expert judgement. In future, we recommend that a more transparent methodology be adopted which will attempt to identify priorities based on a number of criteria, each of which could be given a 'score'. As a first step in this methodology, quantitative assessment of uncertainty in emission factors and activity data used in the NAEI, which is being carried out as part of the NAEI research programme could be used to draw up a list of emission sources/pollutants where emission estimates were subject to most uncertainty. To this measure of uncertainty in the emission estimate we would propose to add an assessment of other factors such as:

- is there a reasonable likelihood that research will lead to improvements in emission factors?
- is the necessary research likely to be costly or not?
- is there a need for more accurate emissions data or are the current estimates, despite their uncertainty, fit for purpose?

An example of how this might work is given in Box 1.

Box 1. A mechanism for identification of emission factor work.

A decision mechanism could involve considering how each improvement option scores for each of four parameters:

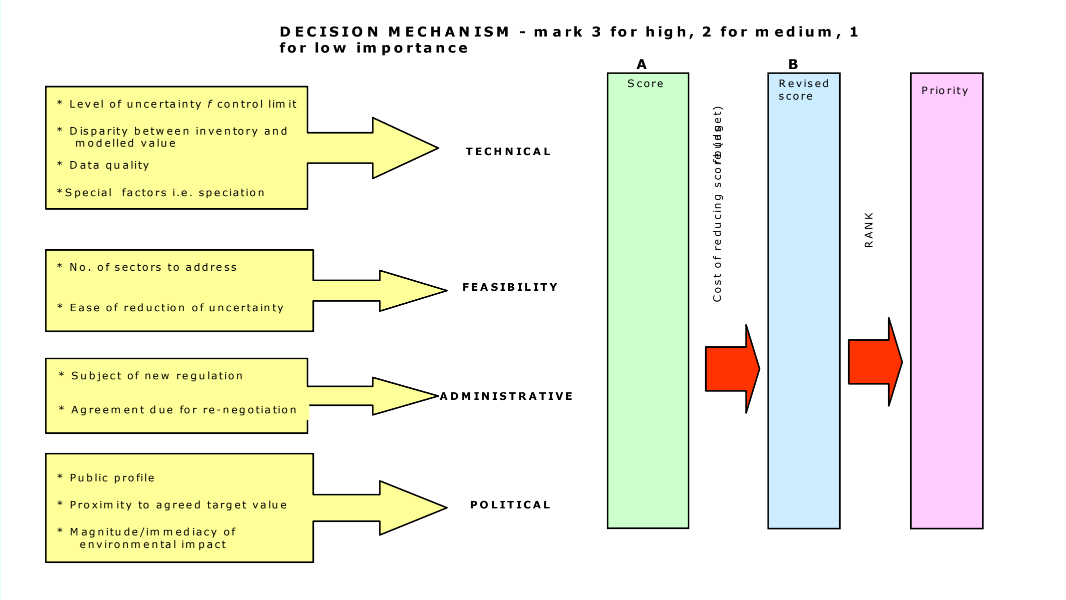
Technical *Each option would be scored depending upon the perceived uncertainty in the existing emission factor/emission estimate. For each pollutant we suggest that a target uncertainty, i.e. an acceptable level of uncertainty, is defined in consultation with DEFRA. For example, a target of +/- 20% might be set for the* NO_X *inventory, in which case an emission factor which is believed to be accurate to +/- 50% would score highly, while one that is +/-25% might only be given the lowest score.*

Feasibility *Each option could be scored depending upon an assessment of the likelihood that research could significantly reduce uncertainty in the emission factor. For example, a low score might be given to a measurement campaign where the technical difficulties in gathering reliable data are high, whereas a high score might be given to a desk-based exercise which involved the collection and analysis of data held by public bodies.*

Administrative *Each option could be scored depending upon an assessment of the extent to which improvement of the emission factor could aid DEFRA in the development of regulations and legislation. For example, improvement of an emission factor for a source that is the subject of new legislation would score highly, whereas research relating to sources which are not covered by current discussions or negotiations would score low.*

Policy *Each option could be scored depending upon an assessment of the importance of improvements to the emission factor in informing Government response to public concerns or large or immediate environmental impacts. For example, recent work to monitor emissions from animal pyres would have scored highly, whereas work to address uncertainty in an area where environmental concerns were considered to have been fully addressed by existing policies.*

The total score could then be modified depending upon the estimated cost of the option, with expensive options being marked down and cheap options being assigned extra points. In this way, options which score high on the first stage of prioritisation might still be rejected if too expensive, whereas lower scoring, but cheap, options might be recommended.



3 Inventory studies

The objectives of this, the smallest task area, were to improve the characterisation and quantification of VOC sources by improving the speciation, and spatial disaggregation of VOC emission estimates in the NAEI. In addition, a preliminary assessment of short term temporal variations in the VOC inventory was to be made in order to facilitate improved ozone modelling.

3.1 VOC SPECIATION

As a result of this programme, the VOC speciation used in the NAEI has been thoroughly reviewed and revised. Two reports detailing progress have been published; Jenkin, Passant & Rudd (2000) and Passant (2001). The species profiles used in the 1999 NAEI have been revised, and further revisions will be made to the profiles used in the forthcoming 2000 NAEI. The NAEI now contains 105 profiles to cover the 314 sources of NMVOC emissions, and these profiles between them contain 697 species or groups of species. As well as collecting new data, effort within this programme has been spent improving the consistency of reporting of species types and in documenting more fully the sources of the profiles. Most sources of NMVOC are now considered to have reasonably reliable speciation for current emissions, and in some cases it is now possible to model how speciation has changed over the years. Some further limited development of the speciation data should be carried out, although the work carried out as part of this project represents a considerable step forward. The VOC speciation data included in the NAEI has been extended to include photochemical oxidant creation potential (POCP) values for all chemical species.

The output of the programme has:

- enabled input to the NAEI ;
- improved modelling capability for ozone
- informed the debate on the role of VOCs in the formation of photochemical oxidants at EU level and hence optimised control strategies in the context of the National Emission Ceilings Directive and the Gothenberg Protocol.

3.2 VOC TEMPORAL VARIATIONS

Estimates have been made of both short term (hourly and daily) and longer term (annual) variations in emissions of VOCs. Details of the methods and results were published in Jenkin, Murrells, & Passant (2000). This report also describes how, as part of another DEFRA research programme, these temporal VOC factors have been used in DEFRA's Photochemical Trajectory Model (PTM), in conjunction with 1998 NAEI emissions data, and data for other European countries given on the EMEP website. As a direct result of incorporating the temporal factors, the model is able to recreate some of the features of the observed pattern of ozone exceedences with day of week which have been reported previously (Jenkin et al., 2000).

3.3 DEVELOPMENT OF POINT SOURCE DATA

In order to improve the spatial disaggregation of VOC emissions in the NAEI, this research programme has provided estimates of emissions from hundreds of individual point sources for use in the mapping work carried out as part of the NAEI. Details of the sources covered have been given in Passant (2000). The number of NMVOC point sources has been extended by almost 1900 as a result of the work carried out as part of this programme.

3.4 PRIORITY AREAS FOR FURTHER RESEARCH

The VOC speciation module of the NAEI contains reasonably robust species profiles for most significant sources. Further effort would not bring large improvements in the reliability of the data without a significant amount of expenditure on source sampling and analysis. Although some measurement work might be worthwhile, in the absence of agreed VOC profiles at European level, it is not clear to us whether the increase in the reliability of the VOC speciation which might be achieved by more widespread measurement work would be worthwhile. For the moment, we recommend that further VOC speciation work is limited to an on-going, limited programme of desk-based research which maintains contacts with trade associations and other experts, encouraging the flow of information into the NAEI speciation module.

The VOC temporal variation module of the NAEI has been developed largely based on AEA Technology experts' estimates of the spread of emissions from hour to hour and day to day. Nonetheless, we are confident that it is reliable enough for use in current models of ozone formation and that, until a new generation of models exist which can make use of more detailed data, further work is not warranted at present.

The spatial disaggregation of NMVOC emissions has been much improved as a result of this programme of research. Despite this, the mapping of NMVOC emissions still relies to a greater extent on the use of 'surrogate statistics' than is the case for most other pollutants. This is due to the fact that a significant proportion of NMVOC emissions are from small industry and domestic sources which are too numerous to be treated as point sources. As a result of this, we recommend that the mapping of those other NMVOC sources which can be treated as line and point sources is given a high priority. In particular, we recommend that mapping data for those sources which are subject to emission controls be reviewed periodically so that any reductions in emissions from these controlled sources can be accurately reflected in the NAEI maps.

4 Cost Curves

4.1 DESCRIPTION OF WORK

Cost data have been collected for the following pollutants:

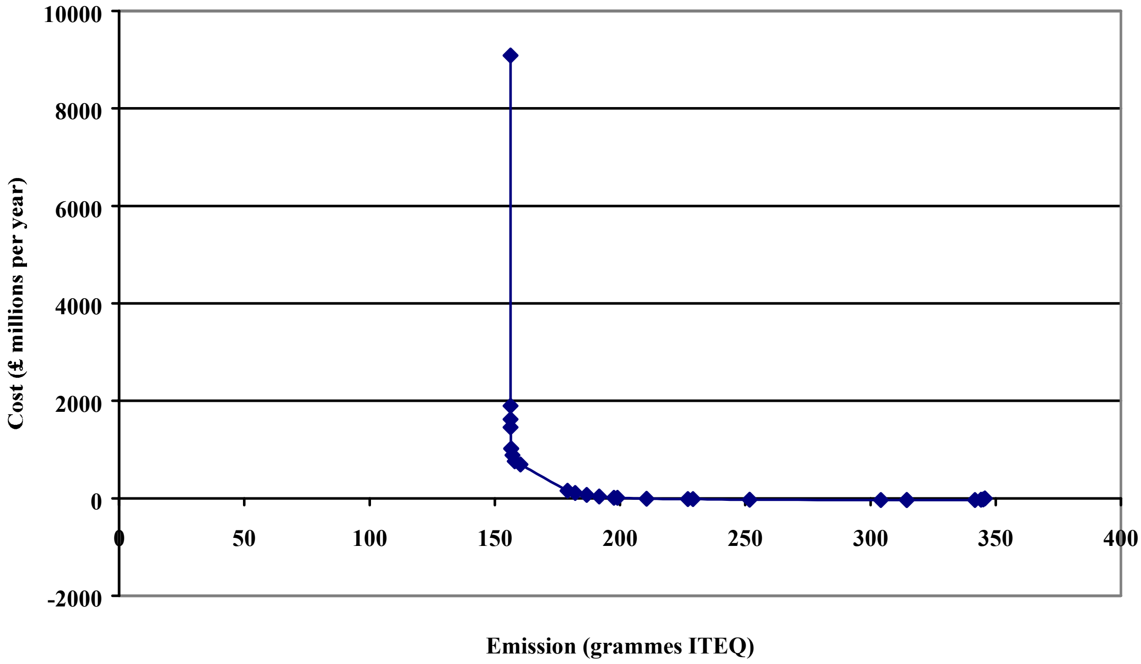
- PM_{10}
- arsenic
- cadmium
- chromium
- copper
- lead
- mercury
- nickel
- selenium
- vanadium
- zinc
- dioxins & furans
- polycyclic aromatic hydrocarbons

Capital and operational cost data have been collected through examination of the literature and through consultation with industry, both directly and through trade associations. In addition, a separate DEFRA contract for AEA Technology to develop cost curves for particulate matter has been a source of reference data. An interim report was produced in early 2000 and a final report in late 2001 (Peirce, Jones, Passant & Holland, 2001, available on DEFRA's Air Quality Archive at http://www.aeat.co.uk/netcen/airqual.

The cost data has been entered into a software tool, developed using Microsoft Access, to rank the abatement measures identified and to present the data as cost curves. Microsoft Access is a relational database management system with a sophisticated user interface, which makes the development and maintenance of this sort of tool reasonably simple. It is also already used to store NAEI data, which is the source of emissions data used in the cost curves. In future it would be possible to link the cost curve tool with the NAEI directly, either by importing the cost curve tool into the NAEI database, or by modifying the cost curve tool to link to NAEI data tables.

The cost curve tool allows the generation of single-pollutant cost curves and weighted-mix, multi-pollutant, curves. Figure 1 is an example of a single-pollutant curve – in this case, it is for dioxins. The available control measures are ranked solely on the basis of their cost effectiveness at reducing emissions of dioxins. No account is taken of reductions made in emissions of metals, other persistent organic pollutants, and particulate matter.

Figure 1 Single-pollutant cost curve for dioxins



The weighted mix cost curves can be used in two ways:

- To assess strategies aimed at controlling a number of pollutants simultaneously (true weighted mix).
- To see how measures aimed at reducing a single pollutant affect emissions of other pollutants ("side-effects").

The first way involves assigning a numerical weighting to a number of pollutants according to the perceived importance of addressing these pollutants. It should be noted that this must currently be done in a completely subjective way, since the cost curve tool does not include any modelling of quantifiable benefits which might, in future be used to weight abatement options for multiple pollutants.

As an example, perhaps emissions of mercury are considered unacceptable, dioxins are a concern, zinc is a minor issue, and all other pollutants are at tolerable levels. In this case, you would want to give a high priority to measures for controlling mercury, medium priority to measures that abate dioxins, and low priority to those that only affect zinc. You can express these priorities as numerical weightings, as in Table 17. Note that the total of the weightings is exactly 1.

Table 17. Example Weightings

Pollutant	Weighting
Mercury	0.6
Dioxins	0.3
Zinc	0.1
Others	0
Total	1.0

The software tool which has been developed uses these weightings to develop a cost curve that shows the most cost-effective way of meeting the combined target, prioritising the measures according to their effects on the different pollutants as described above. By setting the weighting for a single pollutant to 1 and the weighting for all other pollutants to zero, it is also possible to examine side-effects of measures aimed at reducing emissions of a single pollutant.

Cost curves for benzene and 1,3-butadiene have also been developed based on AEA Technology's existing VOC cost curves, which in turn are modified versions of those developed at the International Institute of Applied Systems Analysis (IIASA). These cost curves have not been included in the cost curve tool described above. The VOC cost curves were produced as part of other DEFRA research contracts, relating to the assessment of costs and benefits of the UK adopting emission ceilings under the National Emission Ceiling Directive (NECD). These were converted to benzene and 1,3-butadiene cost curves by assuming that VOC control measures in the VOC cost curve were equally effective at reducing emissions of benzene and 1,3-butadiene. The existing VOC cost curve was based on the 1998 NAEI but has been updated to take account of changes in the 1999 NAEI (thus a VOC cost curve based on the 1999 NAEI is also an output of this project).

4.2 UNCERTAINTIES IN COST CURVES

4.2.1 Sources of uncertainty in the cost-curves

The scope of the cost curve research was to identify the sources and emissions of trace air pollutants and to identify and cost possible measures to control them. The cost-curves so generated represent a first step, and should be subject to refinement over time. This section reviews the main uncertainties with the cost-curves as they currently stand, in order to provide focus for future improvement, and to indicate their likely reliability at the present time.

Uncertainty arises at many points in the development of a cost-curve. The key areas where uncertainties arise for TOMPS and heavy metals are:

- Quantification of emissions data and projections
  For most other air pollutants uncertainties at this stage are relatively unimportant, compared to uncertainties at other stages of cost-curve development. However, uncertainties are (proportionally) larger for trace pollutants, partly because of the use of non-continuous monitoring, and partly because of variability in emissions according to the quality of input materials, systems maintenance, etc.

- Identification of abatement options
  Ideally a cost-curve would include all potential abatement options for reducing the pollutant

in question, though this is rarely possible in practice. In this study, for example, no account has been taken of the potential for significant technological such as the introduction of fuel cells that could have a major impact on emissions.

Any omission is likely to have two effects on the cost-curve. First, the maximum feasible reduction in emissions will be underestimated. Second, the estimated costs of reaching any given level of emissions control may increase (if cheaper options could be applied to reach a particular point than those included in the cost-curve). Clearly, therefore, this source of error will bias towards overestimation of costs and future emissions.

- Applicability of abatement techniques.
  Uncertainties in applicability vary according to the source and abatement technique under consideration. For sectors that cover large industrial installations (e.g. iron and steel, power generation, refineries) the existing state of technology is well characterised and the potential for further refinement reasonably well understood. Problems increase as one starts to consider technologies deployed in smaller installations (e.g. small industrial processes or the residential sector), and cases where technologies have a very long life expectancy (this would include the residential sector, but exclude transport). The problem is probably most marked in this report with respect to energy efficiency options, which, in view of their importance to the cost-curves, are discussed in a separate section below. Overall, the likely bias from this source is towards underestimation of costs and future emissions as a result of the uncertainty in applicability of energy efficiency options.

  Some options will not be available at all sites– this being the case for fuel switching to natural gas at some plant where the existing gas infrastructure is not sufficient to cope with major new sources of demand at the present time. [This does, of course, raise another uncertainty – will the infrastructure be developed over time to be able to satisfy demand, possibly as a result of legislation to control emissions.]

- Efficiency of abatement techniques
  In general, the efficiencies of techniques, and certainly those applied to the major sources (stationary combustion; transport) are relatively well known for TSP and PM_{10}. Therefore, in the context of the report on PM_{10} abatement (Holland *et al*, 2001), it was considered that this source of uncertainty was relatively unimportant. In the context of trace pollutant control, it is more problematic, as heavy metals, dioxins and PAHs tend to associate with particular size fractions of particles, and information on abatement of each size fraction by each different control option is generally lacking. In this report it is assumed that abatement efficiencies for each species will be the same as for PM_{10}, with the exception of Hg where a 50% efficiency has been adopted[1]. This assumption is reasonable for low-volatility metals such as As, Cu, Cr and V. However, it is less satisfactory for semi-volatile species such as Cd, Pb, POPs, Se and Zn which may be concentrated on particles less than 2.5 microns in diameter. Also, for Hg, which is emitted as a gas.

  Here, we make a general estimate of 50% uncertainty in estimates of abatement efficiencies. We accept that this will overestimate uncertainty for the less volatile species (e.g. As, Cr, Cu

[1] Recent work on mercury speciation suggests that the 50% figure is too high by a considerable margin. For most sources a figure of 5 or 10% would appear more appropriate.

and V, as already mentioned), and underestimate uncertainty for the more volatile species (e.g. mercury, and some of the PAHs, such as fluoranthene).

- Technology unit costs
  For large stationary sources, the costs of many of the measures are derived from UK BAT or the BREF notes, and so have been subject to careful and widespread review by industry and regulators. However, these costs are for representative firms and will likely to vary according to the size of industry and plant. Uncertainties are higher for other sectors which have so far been subject to a lower level of analysis and review in the context of IPPC.

  There is evidence that estimated abatement costs tend to fall over time - for example as more suppliers enter the market creating competition and development costs are recouped. Furthermore costs may decrease as the market for a given technique matures. Finally, it may be difficult to know how to attribute the cost of an abatement technique if it reduces emissions of other pollutants concurrently, or if measures would be undertaken in any case through IPPC.

4.2.2 Quantifiable uncertainties

A formal uncertainty analysis was not carried out specifically for this study. However, given similarities in the measures available for control of the trace pollutants of interest here as for PM_{10}, it is possible to use earlier work on particle control (Holland *et al*, 2001) to derive a first estimate of the overall reliability of the data generated. Accordingly parts of that study are reproduced below, with additional commentary to make the findings more relevant to this report.

A previous study on the potential and costs for abatement of ammonia from non-agricultural sources (Handley *et al*, 2001) demonstrated that the use of Monte-Carlo techniques greatly reduces the range in estimates, compared to the simpler approach of combining all high estimates and all low estimates to generate ranges. Holland *et al* therefore applied Monte-Carlo analysis on the national cost-curve for reductions in PM_{10} emissions in 2010 to take into account uncertainty in the following factors:

- costs (£ per tonne) of abatement technologies.
- baseline emissions;
- efficiency of abatement technologies;
- applicability of abatement technologies;

Quantification of the uncertainties in the above factors for individual emission control options is constrained by available data. In some cases (though by no means all), for example, it is necessary to draw on single estimates of costs for a given technology – information that cannot provide guidance on the potential spread of data. However, some estimation of likely uncertainties can be made by drawing on the ranges defined for other measures. The method is not perfect, but at the same time, it is clearly preferable to an assumption of no uncertainty.

The analysis was carried out in two parts. First, the effects of the combined uncertainties of the costs of abatement were assessed (Figure 2). The second analysis looked at the other three factors listed above (Figure 3). In both cases the analysis was based on a 'high' cost scenario for transport options. The figures describe the 90% confidence interval around the best estimate.

Simultaneous analysis of all sources of uncertainty was not carried out, though could be factored into future exercises of this nature.

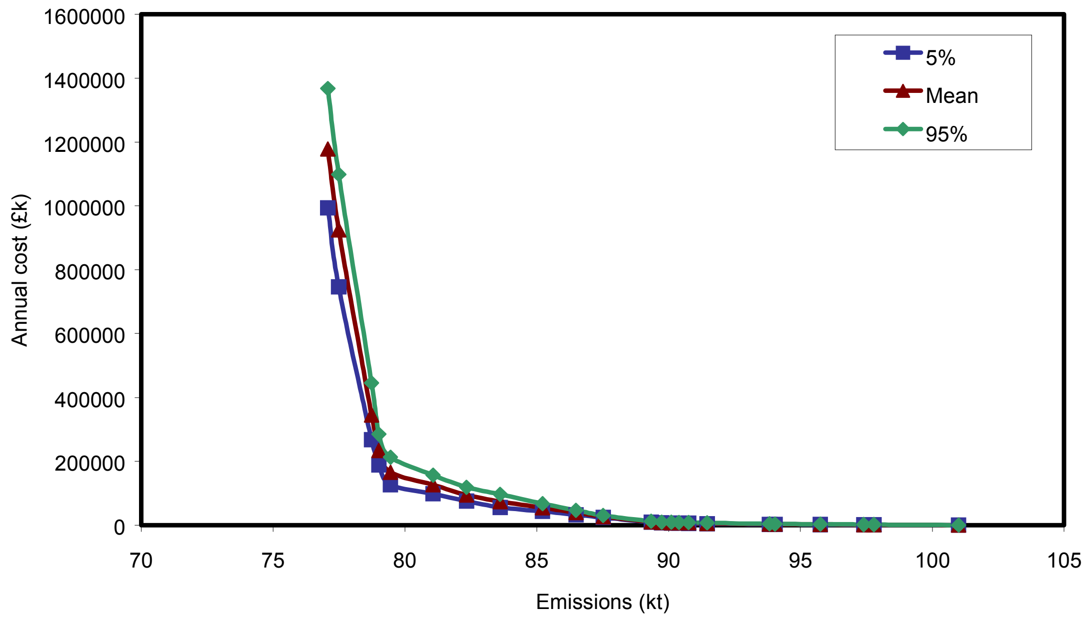


Figure 2 – The impact of uncertainty in costs of abatement measures on the total annual costs of the measures contained in the PM_{10} cost-curve (Holland *et al*, 2001).

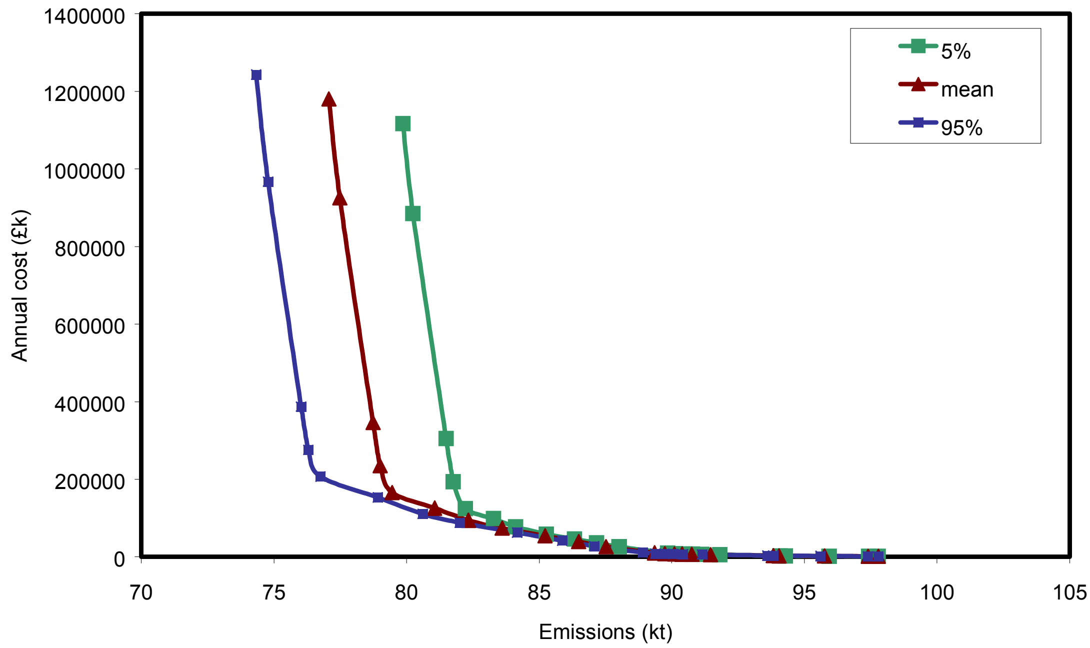


Figure 3 – The impact of uncertainty in abatement levels on the total annual costs of the measures contained in the PM_{10} cost-curve (Holland *et al*, 2001).

Figure 2 demonstrates that there is a maximum uncertainty (as 90% confidence interval) in the costings of +30%, -24% around the mean. Results in Figure 3, to the extent that measures are comparable between the two studies, suggest a similar (additional) level of variation in emissions data.

Having seen these data for PM_{10}, it is necessary to consider how they might apply to the pollutants considered here, bearing in mind that there is greater variability in emissions data and the likely efficiency of options, depending on the effectiveness of measures in controlling the specific particle fractions in which each trace pollutant will preferentially concentrate. Without firm data on the latter in particular, it is not possible to come to a view that is well supported by available information. However, we make a conservative estimate that, for the uncertainties considered to this point, errors in costs and emissions are likely to be twice as high for the trace pollutants as for particles, giving a 90% confidence interval around the best estimates so far derived of ± 60%. This is not intended as the final word on this matter, but does provide some guidance prior to a more complete investigation of the problem.

Uncertainties will of course vary between pollutants, with information on some, not surprisingly, being of a higher quality than for others. For example, uncertainties in baseline emission estimates will be greater for those pollutants for which sources are less well characterised, for example where emissions are dominated by industrial processes rather than fuel use. Such pollutants include Cd, Cr, Hg, Se and Zn. Fugitive emissions pose a particular problem as the difficulties in including them in the NAEI (through imperfect reporting systems) introduce a tendency for underestimation in baseline emissions. In the same area, there is additional uncertainty through possible incompleteness of the inventory, and possible misunderstanding of the importance of historical residues. This seems likely to be of limited significance but could be important for POPs.

The analysis presented thus far does not include consideration of the effects of variation in the discount rate. Given that the choice of discount rate is typically made on an either/or basis, rather than considered through continual ranges this is best done using sensitivity analysis. Moving from a rate of 6%, consistent with current Treasury guidance, to 3% would reduce overall costs for an average measure by about 20%. The measures most sensitive to discount rate are those with high initial costs and low operating and maintenance costs. For measures for which initial costs are low, there is, not surprisingly, little difference in costs between the two discount rates. Further information is provided by Holland *et al* (2001).

It is clearly essential that account is also taken of issues that cannot currently be quantified with a reasonable level of confidence, as is done below. Although there is no satisfactory basis for quantifying the effects of these uncertainties in this report they should not be forgotten.

4.2.3 Uncertainty in the applicability of energy efficiency measures

The existence of variability in the applicability of some measures was discussed above, specifically in relation to fuel switching and current issues of gas supply. In the context of this report the problem is probably most pronounced in relation to energy efficiency measures. As the cost-curves show, these could lead to significant cost-savings whilst at the same time reducing emissions. It is sometimes said that there is now very limited potential for additional energy and other efficiency measures to be introduced. However, this is not the case – as the best practice programmes for the UK Government have demonstrated over many years.

Accepting that there is *potential*, however, is not the same as saying that people will be willing to undertake the measures identified. There may be several reasons why uptake of measures is limited, including but certainly not limited to, the following.

- Lack of awareness of the benefits of energy efficiency, or a lack of belief in claimed financial benefits.
- Inaffordability of the high initial costs of some energy efficiency measures. Unfortunately this may apply most to those living in properties where energy efficiency measures could be most beneficial. Some may simply be put off by high initial costs, even though they could afford them.
- Personal estimates of the useful life of equipment or the length of time that people may live in a particular property – are they long enough to recoup costs?
- Unwillingness to accept the disruption caused by significant building works (e.g. replacement of windows).

The study by Holland *et al* (2001) omitted energy efficiency measures on the grounds that the level of uncertainty in associated uptake and hence costs and emission reductions were too great to be used in a study which was to be applied directly and immediately in relation to the IGCB's (2001) review of the Air Quality Strategy. The issue was discussed in the context of a probable underestimation of the potential for abatement and reduction in control costs, but not taken further. In the context of this study, however, it is appropriate to include the measures in order that the issue is properly debated. For future work, it is recommended that a more extensive review of the potential for energy efficiency is undertaken, in consultation with relevant government departments in particular, as these are already driving forward policy in this area.

4.2.4 Unquantified uncertainties

These arise from the following sources:

1. Omission of options, either because of advances in existing technologies (e.g., replacement of heavy metals by other chemicals, for example for use as stabilisers in some plastics, or in battery manufacture), radical technological change (e.g. introduction of fuel cells in vehicles), or a lack of data on current application of a valid option
2. Availability of some non-technical options for reducing emissions in the UK, for example, changing the source of fuels
3. Possible errors in scenarios of future energy use, of the effectiveness in the implementation of existing legislation, and of future market trends
4. The extent to which the costs identified here will be borne as a result of concern over other problems, for example, global warming, particle control, and waste management.

Issues 1, 2 and 4 in this list bias the existing cost-curves towards under-estimation of the maximum feasible reduction in emissions, and to overestimation of the costs of reaching any given level of abatement. Issue 3 may lead to over or under-estimation.

Issue 4 indicates the need for going beyond the concept of single pollutant cost-curves, to a more multi-dimensional framework.. The single-pollutant methodology was adequate for the times when problems and solutions were sensibly addressed on a pollutant by pollutant basis– in other words when certain pollution problems were so manifestly bad that it was clear that they needed to be tackled without reference to anything else. However, the success of action to control pollution means that now it is not nearly so clear where the biggest benefits to be gained through pollution control lie. This study has defined a preliminary method for introducing the multi-pollutant dimension. The methods applied could be extended to include other pollutants also (here, they are confined to heavy metals and TOMPS). Whilst we believe that the method applied here is useful in generating new perspectives on abatement, additional methods, for example, more explicit inclusion of impacts assessment, should also be considered for the future.

Some of the uncertainties listed provide additional ideas for refinement of cost/benefit decision-making models such as the cost-curves generated in this study. It would appear appropriate to develop a much broader scenario-based approach to quantifying such uncertainties in the future – one that could be applied consistently across all pollutants, and be compatible with a statistical treatment of those uncertainties that can be quantified. Such an approach may be useful in identifying areas where alternative approaches to encouraging abatement, such as the use of fiscal incentives, could be useful. It may also assist in defining general levels of risk of different strategies – for example, some approaches may work well only under certain energy scenarios.

4.3 FURTHER WORK

The development of cost-curves is subject to a number of sources of uncertainty, some of which are likely to cause underestimation of potential abatement and/or overestimation of costs, and some which will act in the opposite manner. The acknowledgement and quantification of these uncertainties is in many ways an indication of the growing maturity of cost-curve development - previous use has often given readers a false sense of security in the data presented. Given that the cheapest options for pollution control have generally been adopted already, it is time that a more strategic approach to the application of cost-curves was established to reduce the risks of taking options that are less cost-effective than possible. This needs to go beyond the quantification of individual sources of uncertainty in the cost-curve to include sensitivity analysis around energy and other types of scenario. Such developments need to be considered alongside DEFRA's continuing work on Integrated Assessment Modelling – adding to the transparency of that work, whilst not duplicating it.

Estimates made in section 4.2 of the extent of uncertainties in the cost-curves should be regarded as preliminary, though they do indicate where future refinements may be most useful in reducing uncertainty. The need to factor in other policies more effectively than has been possible here, particularly those relating to climate change (given the potential effect of energy efficiency measures on the cost-curves) and particle control (given the link to most of the pollutants considered here) is suggested as the first priority. A second priority should be improvement of the knowledge of which size fraction of particles each of the pollutants tend to condense onto in the flue gas stream, and through this, refinement of information on the cost-effectiveness of different control options.

The current cost curves include control measures for heavy metals, particulate matter, persistent organic pollutants and volatile organic compounds. The cost data which have been collected are fairly uncertain, and gaps exist where control options can be identified but no cost data have been found. Therefore, a further priority is for an ongoing programme of research to identify any additional control options and to develop more reliable cost data for each option. The cost curves require progressive refinement. The research should be very broad, looking at all major emission sources and consulting widely within industry and other researchers both inside and outside the UK.

The inclusion of cost data for other pollutants in the cost curve tool should be considered. AEA Technology has developed cost curves for benzene, 1,3-butadiene, and NMVOC as part of this research programme, and has also developed cost curves for SO_2, NO_x and non-agricultural sources of NH_3 as part of other DEFRA research projects. With modifications to the cost curve tool, these data could be included, and this would extend the capability of the tool to examine multi-pollutant benefits. For example, flue gas desulphurisation, energy efficiency measures and road transport technical and non-technical measures would all impact both on gaseous pollutants such as SO_2 and NO_x, as well as the particulate matter pollutants already included in the cost curve tool. Efficiencies of abatement options included in the cost curve tool towards other pollutants such as carbon monoxide could also be included relatively easily.

Currently, the cost curves are presented as cost per tonne emission abated. Although this can be useful way of expressing costs of abatement (for example, the cost associated with reaching specific emission levels was important for the assessment of costs and benefits of the NECD), it would be desirable to factor other benefits into the cost curve tool. As an example, the costs of abating emissions of pollutants could be compared with benefits such as reductions in exposure by combining the existing cost curve tool with air quality modelling. With further development it might then be possible to apply dose-response functions to show the environmental damage that can be linked to each pollutant. If these impacts can be monetised or compared quantifiably in some other way, then this would give a method for comparing the costs and benefits of abatement options across all pollutants in a transparent and systematic way.

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Appendices

CONTENTS

Appendix A. Details of emission factor studies during April – September 2001

The following desk-based pieces of research have been carried out in the last 6 months of the research programme and have not been reported previously.

Small scale waste combustion

In order to test whether this source is likely to be significant nationally, some provisional estimates of the quantities of different wastes which are burnt have been made. These estimates have been made by AEA Technology based on estimates of total waste arisings from various sources, including DEFRA, to which we have applied our own estimates of the proportion of waste of each type which is burnt. The provisional estimates are shown in Table A.1.

Table A.1 Provisional estimates of quantities of waste burnt (in tonnes)

Waste type	Domestic fires	Bonfires	Industrial fires
Paper & card	75,600	2,360	19,700
Plastics	7,640	2,360	9,970
Textiles	2,610	2,360	-
Putrescibles	25,100	106,000	-
Treated wood	5,100	2,360	1,220
Untreated wood	5,100	2,360	2,720

These figures should be used with available emission factors to determine whether these sources might be significant.

Wood impregnation

The aim of this research was to investigate whether any detailed activity data were available on the supply of creosote and other wood preservatives to UK businesses. Trade associations and companies operating in the manufacture and supply of these products were contacted, some useful data being obtained.

The Creosote Council suggested that current UK consumption of creosote was about 25 ktonnes per year, which is % lower than the current NAEI estimate of 30 ktonnes. Since the NAEI figure is extrapolated from an estimate of creosote use in

1990 on the basis of the output of the wood and wood products industry, the figure supplied by the Creosote Council must be considered more reliable and is recommended for use in the 2000 NAEI. The Creosote Council also questioned the current NAEI assumption that 10% of creosote was emitted to atmosphere, considering this excessive. Consideration should be given to carrying out measurements to obtain a better emission factor for emissions from creosote-treated wood, but we make no recommendation for changes to the NAEI emission factor at present.

One UK supplier of solventborne preservatives provided an estimate of the UK market for solventborne preservatives for industrial users of 3 million litres (equivalent to 2.4 ktonnes). This figure is very much lower than the figures used in the NAEI at present (approximately 19 ktonnes in 1999). It is also very low compared with estimates of solvent supplied to the wood preservation sector, which have been supplied by the Solvent Industry Association (29 ktonnes in 1998/99). In the absence of further data, it is not possible to make any conclusion as to which of these conflicting data are most reliable. Further research could be considered, although a better approach might be to identify users of solventborne preservative and to gather emissions data from each one. Data for Part A processes in England and Wales is available from the Pollution Inventory. In addition, 38 local authorities use PG 6/3, the process guidance note relating to chemical treatment of wood, in the regulation of one or more processes, according to a survey carried out by DEFRA (AQ1(00)). This number is sufficiently small that it would be feasible to contact these local authorities in order to obtain information on which to base more accurate emission estimates. The Scottish Environment Protection Agency (SEPA) also regulate a small number of processes and might be able to supply emissions data for these.

Rubber processes

The purpose of this research was to obtain up-to-date information on the solvent usage and emissions from processes in the NAEI sector 'other rubber processes' The British Rubber Manufacturers Association (BRMA) have provided an estimate of the solvent use by this sector (described as the general rubber goods (GRG) sector) of 2 ktonnes. This figure is based on the results of a survey which suggested that solvent use by processes in this sector averaged 65 tonnes per year. The new BRMA figure compares with an estimate of 4.75 ktonnes in 1993 for their members (who represented 80% of the sector). The BRMA figures do not include emissions from tyre manufacturers (covered by a separate NAEI sector) or the production of retreaded tyres (not currently included in the NAEI). Although, we have contacted the Retread Manufacturers Association, no data on emissions from this sector have been obtained. However, the BRMA believe that emissions from this sector will be small, since 'very little' solvent is used. The BRMA figure for the GRG sector also includes a number of processes which are currently included in the NAEI sector 'textile coating'. These processes are listed below:

Day International (UK) Ltd, Dundee
Farnbeck Ltd, Edinburgh

The Gates Power Transmission Ltd, Dumfries
Dunlop Precision Rubber, Charnwood
Metflex Schlumberger Ltd, Hyndburn
Lila Hurst Ltd, Kirklees
White Cross Rubber Products Ltd, Lancaster
A.O. Ferguson & Co Ltd, Oldham
Proofing Technology Ltd, Rochdale
Duco International Ltd, Slough
Dowty Woodville Polymer Ltd, South Derbyshire
Duco International Ltd, Swindon
Hi-Tec Rubber Coatings Ltd, Wigan
James Walker & Co Ltd, Woking

Emissions from a number of these processes is high and the total emission from these sites may be close to or in excess of the 2 ktonnes suggested by the BRMA for the whole sector. Some further research may be necessary in order to resolve this issue, for example by obtaining industry estimates of the proportion of solvent used by textile coating and non textile coating processes.

Screen wash

The purpose of this research was to obtain verification for the data currently used in the NAEI for the quantity of screen wash used annually. No trade association has been found for suppliers of automotive products such as screen wash and, although a number of companies involved in the supply of these products were contacted, none were able to supply any data. Those that expressed any opinion of the validity of current assumptions in the NAEI were broadly in agreement and so no recommendation is made for any changes to the estimates for this sector. Further research on this issue would be worthwhile if further contacts could be identified.

Fletton bricks

The purpose of this work was to develop emission estimates for process emissions from Fletton brickworks. Emissions from the combustion of fuels by brickworks is already included in the NAEI under the category 'other industry combustion' but emissions released from the clay being fired is not. Emissions data for all Fletton brickworks is included in the Pollution Inventory and these data will include both the fuel combustion emissions and the process emissions. The approach adopted therefore was to estimate fuel usage by the brickworks, apply NAEI emission factors to these fuel usage data to obtain estimates of the fuel combustion emissions, and treat the difference between the Pollution Inventory data and these estimates as process emissions. Estimates were also made of the tonnages of Fletton bricks produced each year. The emission factors, activity data and emission estimates for 1999 are given in Table A.2

Table A.2 Emission factors, activity data and emission estimates for Fletton brickworks in 1999

Pollutant	Emission factor (kg/t)	Activity (Mt)	Emission (kt)
Carbon dioxide	22.4	1.133	25.4
Methane	0.518	1.133	0.587
Carbon monoxide	1.34	1.133	1.52
Sulphur dioxide	7.91	1.133	8.97
NMVOC	0.516	1.133	0.585
PM_{10}	0.231	1.133	0.262
Hydrogen fluoride	0.122	1.133	0.139

We recommend that these data are incorporated into the NAEI.

Identification of processes emitting SO_2 and CO

The Environment Agency have provided copies of authorisation documents for processes they regulate under the Integrated Pollution Control (IPC) regime. These documents have been surveyed to identify those processes principally falling within the metals and chemicals industries which emit sulphur dioxide or carbon monoxide as a result of a process other than fuel combustion. As a result, a number of process types were identified including soda ash production, carbon black manufacture, use of sulphuric acid which emit one or both pollutants. New emissions data, based on Pollution Inventory data, have been included in the 2000 NAEI as a result.

Emissions from car manufacture, drum coating, leather coating and manufacture of pressure sensitive tapes.

The purpose of this research was to collect up-to-date information on solvent use and emissions from the following processes regulated by local authorities:

- coating as part of a process of car manufacture;
- drum coating;
- leather coating;
- manufacture of pressure sensitive tapes.

As with previous studies of this kind, the results of this research would be used both to update emission estimates in the NAEI but also as input to the mapping of NMVOC emissions. Information was received for most of the significant sources and as a result detailed emissions data have been recommended for use in the NAEI. A summary is given in Table A.3

Table A.3 Summary of data collected on Part B processes

Sector	No of sites (2000)	Emission (ktonnes)
Car coating	20	8.890
Drum coating	32	0.867
Leather coating	13	0.356
Pressure sensitive tapes	8	1.371

Appendix B Organisations providing data for inventory improvements

The following organisations provided help and data used to improve emission factors, emission estimates used in the NAEI or cost curves during the period 1998 – 2001 as part of this research programme.

Regulators

Scottish Environment Protection Agency
Environment Agency
Local Authorities:

- Adur
- Allerdale
- Amber Valley
- Ashfield
- Ashford
- Babergh
- Barking and Dagenham
- Barnsley
- Basildon
- Bath & North East Somerset
- Bedford
- Bexley
- Birmingham
- Blackburn with Darwen
- Blaenau Gwent
- Blyth Valley
- Bolton
- Boston
- Bradford
- Braintree
- Breckland
- Brent
- Bridgnorth
- Broadland
- Broxtowe
- Burnley
- Bury
- Caerphilly
- Calderdale
- Carlisle
- Carrick
- Charnwood
- Cheltenham
- Chesterfield
- Christchurch
- Congleton
- Copeland
- Corby
- Crewe and Nantwich
- Dacorum
- Derby
- Derbyshire Dales
- Dudley
- Durham
- Ealing
- Easington
- East Lindsey
- East Staffordshire
- East Yorkshire
- Eastleigh

Ellesmere Port and Neston
Epping Forest
Erewash
Fareham
Flintshire
Gateshead
Gedling
Gosport
Guildford
Hackney
Halton
Harlow
Harrow
Hartlepool
Hastings
Havering
Herefordshire
High Peak
Hounslow
Huntingdon
Hyndburn
Kings Lynn & West Norfolk
Kingston Upon Hull
Kirklees
Knowsley
Lancaster
Leeds
Leicester
Liverpool
Luton
Macclesfield
Malvern Hills
Manchester
Medway
Mendip
Merton
Mid Devon
Milton Keynes
Monmouth
Neath Port Talbot
New Forest
Newcastle Upon Tyne
Newham
North East Lincolnshire
North Hertfordshire
North Lincolnshire
North Somerset
North Tyneside
North Warwickshire
Northampton
Norwich
Nuneaton and Bedworth
Oldham
Pendle
Plymouth
Poole
Powys
Preston
Reigate and Banstead
Rhondda-Cynon-Taff
Rhymney Valley
Ribble Valley
Rochdale
Rossendale
Salford
Sandwell
Scarborough
Sedgefield
Sedgemoor
Sefton
Selby
Slough
Solihull
South Bedfordshire
South Buckinghamshire
South Cambridgeshire
South Derbyshire
South Gloucestershire
South Kesteven
South Ribble
South Somerset
South Tyneside
Southampton
Southend-On-Sea
Southwark
St Helens
Stafford
Staffordshire Moorlands
Stockport
Stockton-On-Tees
Stoke-On-Trent
Stroud
Sunderland
Swansea
Swindon
Tameside

Test Valley
Tewkesbury
The Wrekin
Thurrock
Tonbridge and Malling
Torfaen
Trafford
Uttlesford
Vale of White Horse
Wakefield
Waltham Forest
Watford
Wear Valley
Wellingborough
West Berkshire
West Dorset
West Lancashire
West Lindsey
West Somerset
West Wiltshire
Wigan
Windsor and Maidenhead
Wirral
Woking
Wolverhampton
Worcester
Wrexham Maelor
Wychavon
Wycombe
York

Trade Associations

Association of Electricity Producers
British Adhesives and Sealants Association
British Aerosol Manufacturers Association
British Cement Association
British Coatings Federation
British Glass Manufacturers Confederation
British Leather Confederation
British Lime Association
British Non-Ferrous Metals Federation
British Printing Industry Federation
British Rubber Manufacturers Association
British Wood Protection and Damp-proofing Association
Chemicals Industry Association
Cosmetics, Toiletries and Perfumery Association
Country Landowners Association
Creosote Council
Crop Protection Association
Electricity Association
Energy From Waste Association
European Chlorinated Solvents Association
European Coil Coating Federation
Federation of British Cremation Authorities
Film Coating Industry Group
Institute of Bakers
Institute of Petroleum
Lead Development Council
Made-Up Textiles Association
Metal Packaging Manufacturers Association
Refined Bitumen Association
Retread Manufacturers Association

Scotch Whisky Association
Screen Printing Association
Society of Motor Manufacturers and Traders
Solid Fuel Association
Solvent Industry Association
Textile Services Association
Timber Growers Association
UK Steel Association
United Kingdom Offshore Operators Association
United Kingdom Petroleum Industry Association
Zinc Association

Companies

Associated Octel
BP Chemicals Ltd
Britannia Zinc Limited
British Sugar Ltd
Brittania Zinc Ltd
Ciba Speciality Chemicals
Coalite
Corus UK Ltd
CPL Industries
Distillex Ltd
Elementis Chromium
Enichem Chemicals Ltd
Glaxo Wellcome Ltd
Hamworthy Combustion Engineering
Hays Chemicals
Heating Equipment Testing and Approval Scheme Ltd
ICI Chemicals and Polymers
ICI Chlor Chemicals
Innogy plc
Rhodia Eco Services
Shanks Chemicals Ltd
Shell Chemicals Ltd
Tate & Lyle Ltd

Other organisations

Forestry Commission
Department of Trade and Industry
Environmental Industries Commission
National Trust
Ofgem
IMechE Environmental & Safety Engineering group

Appendix C Priority areas for emission factor development

The following are recommended as priority areas for further development of emission factors

Acidification/eutrophication/ground level ozone (Gothenburg Protocol, NEC Directive etc.)

<u>Ammonia</u>

High

- Improved ammonia emission estimates for landfills.
- Improvement of emission factors for sewage treatment.

Medium

- Review of emission factors for food industry processes and Part B processes.

Low

- Development of additional point source data for sources of ammonia.

<u>NMVOC</u>

High

- Improved emission factors for food industry processes.
- General updating of emission factors for NMVOC sources that are subject to emission controls.
- Periodic updating of information on emissions from individual point sources included in the NAEI.
- Improved emission estimation methodologies for some categories of solvent use.

Medium

- Improved species profiles for sectors where current profiles are uncertain.

Low

- Improvement of historical estimates for sources where the current approach is insufficiently robust.

Hydrogen Chloride

Medium

- Development of improved emission factors for process emissions

Hydrogen Fluoride

Low

- Improvement of historical emission estimates for brick manufacture.
- Development of emission factors for any processes not already included in the NAEI

NOx

No priority areas.

SO_2

No priority areas.

Air Quality Strategy

Particulate matter (PM_{10}, $PM_{2.5}$, PM_1 etc.)

High

- Improvements in size distribution profiles for sources of particulate matter.

Medium

- Periodic review of emission factors for particulate matter from industrial processes, including fugitive sources.
- Improved emission factors for small combustion processes

Low

- Improved emission factors and activity data for Part B processes.

Benzene

Medium

- Review emission factors for industrial processes.

1,3-butadiene

Medium

- Review emission factors for industrial processes.

Carbon monoxide

Low

- Measurement of emission factors for some stationary combustion sources.

Lead

Medium

- Periodic review of emission factors for heavy metals from industrial processes, including fugitive sources.
- Development of additional point source data for major sources of lead

Low

- Improvement & review of emission factors for fuel combustion.

Benzo[a]pyrene

High

- Improved speciated emission factors for combustion processes.
- Improved speciated emission factors for creosote use.
- Further development of emission estimates for accidental fires and burning of wood waste.

Medium

- Speciated emission factors for bitumen production and use.
- Improvement of spatial disaggregation for polycyclic aromatic hydrocarbon emissions.

Hazardous air pollutants

Heavy metals

High

- Improved species profiles for mercury, chromium and nickel.
- Improvement & review of emission factors for fuel combustion.

Medium

- Improved emission factors for certain Part B processes.
- Development of additional point source data for major sources of heavy metals
- Analysis of heavy metal contents of some fuels
- Periodic review of emission factors for heavy metals from industrial processes, including fugitive sources.

Low

- Measurement/assessment of emission factors for waste burning and accidental fires.

PCDD/PCDF

High

- Further development of emission estimates for accidental fires and burning of wood waste.
- Improved speciated emission factors for combustion processes, in particular small combustion processes.
- Improved speciated emission factors for clinical waste incineration.

Medium

- Improved speciated emission factors for ferrous and non-ferrous metal industry processes.
- Improved speciated emission estimates for chemical industry processes.

Low

- Improved speciated emission factors for other sources of dioxins/furans.

PAH

High

- Improved speciated emission factors for coke and SSF production.
- Improved speciated emission factors for combustion processes.
- Improved speciated emission factors for creosote use.
- Further development of emission estimates for accidental fires and burning of wood waste.

Medium

- Speciated emission factors for bitumen production and use.
- Improvement of spatial disaggregation for polycyclic aromatic hydrocarbon emissions.

Low

- Improvement of temporal disaggregation for polycyclic aromatic hydrocarbon emissions.

Pesticides (HCH, PCP, HCB)

High

- Improved data on usage of selected pesticides and improvement of emission estimates for HCB in particular resulting from pesticide uses.

Medium

- Improvement of emission estimation methodology for releases of pesticides from treated wood.

PCB

High

- Further development of speciated emission factors for all major sources of PCBs.

Medium

- Improvement in emission estimates for capacitors and transformers.

Low

- Improvement in emission factors for landfills and incineration plant.

Other pollutants

SCCP

High

- Improvement in emission estimates for all sources, including identification of activity data and assessment of release rates.

PCN

High

- Improved emission factors for electricity generation plant and other large combustion plant.

Medium

- Improved emission factors for chemical waste incinerators.
- Development of emission factors for landfills and general waste incinerators.
- Improved emission factors for small combustion plant.

Low

- Development of emission factors for electric arc furnaces.

PBDE

High

- Improvement in emission estimates for all sources, including identification of activity data and assessment of release rates.

Base cations

Medium

- Development of improved emission factors and activity data for industrial processes.