Report

Summary Report for Project EPG 1/3/195 "Emission Factors for Air Pollutants", Year 2

A report prepared 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 for the Department for the Environment, Food and Rural Affairs; the National Assembly of Wales: the Scottish Executive; and the Department of Environment in Northern Ireland by **netcen** (an operating division of AEA Technology plc) under the contract EPG 1/3/195, “Emission factors for air pollutants”.

The Department for Environment Food and Rural Affairs (Defra) Air and Environment Quality (AEQ) Division is responsible for maintaining the UK National Atmospheric Emissions Inventory (NAEI). The NAEI is maintained by **netcen** on behalf of Defra. As part of the ongoing quality control of the NAEI the quantitative uncertainty in the national emission total of each component pollutant in NAEI is reviewed annually. Based on the findings of this review project EPG 1/3/195 aims to characterise and minimise uncertainty in the emission factors used in the compilation of the NAEI and by association those of other UK inventories. The project has objectives (Tasks) that are set and reviewed annually; these comprise data collection and evaluation via literature review, personal contact with industrial representatives, direct source measurement and other means as appropriate.

This summary report presents a review of Year two tasks, outlines the principal findings and recommendations, and describes the nature of the improvement to the NAEI. The formal reports for each task are available from the Defra research report web site at http://www.airquality.co.uk/archive/reports/list.php

The emission factor improvement tasks for the first year were prioritised according to a ranking procedure based on the magnitude of the current uncertainty, policy relevance, and the cost-effectiveness of resource allocation. Year Two tasks were assessed on a similar basis and comprised the following:-

- Simple desk-based studies
- Overseas cooperation
- A combustion calculator
- Emissions from ‘Other VOC’ sources
- Emissions from garden machinery
- Particulate matter emissions from industrial and combustion processes

Through the completion of these tasks, many emission factor and other inventory changes have been recommended for the NAEI and the overall quality of the emission database has improved as follows:-

- There is a more comprehensive body of information available for compiling the NAEI, and the database is more complete and self consistent as a result.
- The data collected has enabled more accurate estimate of time series.
- Knowledge of the uncertainty of key pollutants has been improved.

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1 Introduction

1.1 PROJECT BACKGROUND

This report has been prepared for the Department for the Environment, Food and Rural Affairs; the National Assembly of Wales: the Scottish Executive; and the Department of Environment in Northern Ireland by **netcen** (an operating division of AEA Technology plc) under the contract EPG 1/3/195 - Emission factors for air pollutants.

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This report summarises the individual tasks, listing findings and noting the improvements to the inventory.

1.2 DEVELOPMENT OF YEAR TWO WORK PROGRAMME

The tasks included in this project include reappraisal of the adequacy of emission factors used in the NAEI and updating the priority list of sources and pollutants in order to improve the overall quality of the NAEI and other inventories that feed from it. This focusing of the work programme was achieved using: the output of NAEI work on uncertainties, recommendations from Year One of the programme, an appreciation of the needs of the NAEI and other data users. Discussion with Defra led to the decision to concentrate work in Year Two on the following:-

1. Simple desk-based studies (Task 1)
2. International activities (Task 6)
3. Combustion calculator (Task 8a)
4. Other VOCs (Task 8b)
5. Garden machinery (Task 8c)
6. PM_{10} and sub-PM_{10} emissions from combustion and industrial sources (Task 9)

1.3 PROGRAMME METHODOLOGY

Project EPG 1/3/195 aims to improve inventory quality by characterising and minimising the uncertainty in the emission factors used in the compilation of the NAEI. The factors that influence an inventory's general quality are its: transparency, completeness, comparability, consistency and accuracy – TCCCA factors. Any of these factors, singly or in combination, can improve or degrade inventory quality. EPG 1/3/195 objectives are directed to systematically examining and then working to strengthen these influences for the better. The work will, as a result, improve the confidence that an inventory user may place, at any one time, in the estimate of the mean emission factor - even if the mathematical expression of its uncertainty goes either up or down.

For the purposes of the emission factors work:-

- Improved ***transparency*** requires that the assumptions and methodologies used for deriving emission factors should be clearly explained so that users can replicate and assess the data suitability for their particular user requirement.

- ***Completeness*** requires that an emission source (and its identifier, code, description etc.) covers all known contributions to the emission that could reasonably be expected to be included. Completeness also covers those data aspects relating to speciation, geographical coverage, and temporal resolution.

- ***Consistency*** requires that any data used is internally consistent in all their elements with data from other years. Emission data are consistent if the same methodologies are used for all years and if consistent data sets are used to estimate emissions.

- ***Comparability*** requires that estimates of emissions are comparable with similar data reported by others. Ideally, data providers and reporters should use standardised, harmonised, methodologies and formats.

- ***Accuracy*** is a relative measure of the exactness of an emission estimate, and requires that essential data are systematically neither over nor under true emissions, as far as can be judged, and that actions have been taken to quantify and reduce uncertainties as far as practicable.

TCCCA influences change and evolve in the course of time as a result of circumstantial changes. The present work seeks to provide:-

- generic descriptive material to enable a user to decide whether inventory suitability criteria have changed to the point where action needs to be taken.

- specific information to feed into the annual review of NAEI uncertainty review.

2 Simple Desk-based Studies

2.1 BACKGROUND

Small, simple, pieces of research were carried out in order to improve detail in parts of the National Atmospheric Emissions Inventory. The task consisted of the gathering of information from industry via telephone contacts with trade associations and industrial process operators as well as via the internet and literature sources.

The research has covered a wide range of areas and, as a result, inventory improvements have been proposed in the following areas:

- Container glass production (PM_{10}, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn);
- Special glass production (PM_{10}, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn);
- Domestic glass production (PM_{10}, As, Cd, Cu, Hg);
- Lead glass production (As, Cr, Cd, Cu, Hg, Se)
- Wood impregnation (VOC);
- Burning of treated wood (Cr, Cu);
- Cement clinker production (All pollutants);
- Film coating (VOC);
- Paper coating (VOC);
- Printing of flexible packaging (VOC);
- Manufacture of pressure sensitive tapes (VOC);
- Adhesives use (VOC);
- Petrol stations and petrol terminals (VOC, benzene, 1,3-butadiene);
- Non-fletton brickworks (PM_{10}, HCl, HF);
- Plaster processes (PM_{10});
- Industrial combustion processes (NOx);
- Tyre manufacture (VOC);
- Slag cement production (PM_{10});
- Foundries (PM_{10}, Cr, As, Cd, Cu, Hg, Ni, Pb, Se, V, Zn, Mn, Sn);
- Copper wire rod plants (CO);
- Sewage sludge incineration (NOx, As, Cd, Hg, Pb, dioxins) ;
- Clinical waste incineration (As, Ni, dioxins)
- Part B processes (PM_{10})

Further specific tasks have included obtaining copies of BREF reports, other publications such as company environmental reports, and miscellaneous background data (e.g. for identification and positioning of point sources) via the internet.

2.2 FINDINGS AND RECOMMENDATIONS

This task has brought about significant improvements to the completeness of NAEI and also the speciation and temporal resolution of sources. The work further enabled our ability to respond to ‘ad hoc’ enquiries from Defra. The number of work items undertaken under this task was greater than provided for in the original work programme. It is recommended that this task is continued for year 3 of the project.

2.3 IMPACT ON INVENTORY QUALITY

Table 2.1 summarises the changes in emission estimates made between the 2001 and the 2002 versions of the NAEI as a result of research carried out as part of this task.

Table 2.1 Changes in emission estimates resulting from Task 1 (Year 2).

Source	Pollutant	Units	Emission	
			2002	2001
Glass (container)	PM_{10}	tonnes	540	39
Glass (container)	Arsenic	kg	-	4.6
Glass (container)	Cadmium	kg	-	5.7
Glass (container)	Chromium	kg	390	91
Glass (container)	Copper	kg	-	23
Glass (container)	Mercury	kg	-	1.9
Glass (container)	Nickel	kg	-	72
Glass (container)	Lead	kg	-	460
Glass (container)	Selenium	kg	11000	690
Glass (container)	Zinc	kg	-	420
Glass (domestic)	Arsenic	kg	-	1.5
Glass (domestic)	Cadmium	kg	-	14
Glass (domestic)	Copper	kg	-	58
Glass (domestic)	Mercury	kg	-	4.8
Glass (lead)	PM_{10}	tonnes	8	19
Glass (lead)	Arsenic	kg	-	170
Glass (lead)	Cadmium	kg	-	0.18
Glass (lead)	Chromium	kg	-	2.8
Glass (lead)	Copper	kg	-	0.7
Glass (lead)	Selenium	kg	-	21
Glass (special)	PM_{10}	tonnes	120	36
Glass (special)	Arsenic	kg	260	12
Glass (special)	Cadmium	kg	-	14
Glass (special)	Chromium	kg	-	230
Glass (special)	Copper	kg	-	58
Glass (special)	Lead	kg	630	1200
Glass (special)	Mercury	kg	-	4.8
Glass (special)	Nickel	kg	110	180
Glass (special)	Selenium	kg	-	1700
Glass (special)	Zinc	kg	320	1100
Wood impregnation (LOSP)	VOC	tonnes	6300	18000
Burning of CCA impregnated wood	Copper	kg	8700	-
Burning of CCA impregnated wood	Chromium	kg	4800	-
Film coating	VOC	tonnes	2600	2800
Textile coating	VOC	tonnes	2000	2100
Flexible packaging	VOC	tonnes	9800	11000
Pressure sensitive labels	VOC	tonnes	560	330
Industrial adhesives	VOC	tonnes	26000	30000
Tyre manufacture	VOC	tonnes	1400	1500
Non-Fletton brickworks	HCl	tonnes	240	-
Non-Fletton brickworks	HF	tonnes	310	-
Slag cement grinding	PM_{10}	tonnes	43	-
Industrial combustion of coal	NO_x	tonnes	7800	9400
Industrial combustion of fuel oil	NO_x	tonnes	3000	4600
Industrial combustion of gas oil	NO_x	tonnes	7100	7200

Table 2.1 Changes in emission estimates resulting from Task 1 (Year 2).

Source	Pollutant	Units	Emission	
			2002	2001
Industrial combustion of natural gas	NO_x	tonnes	48000	50000
Coal-fired autogenerators	CO	tonnes	3600	6600
Coal-fired autogenerators	NO_x	tonnes	11000	7000
Coal-fired autogenerators	Arsenic	kg	71	6000
Coal-fired autogenerators	Cadmium	kg	10	140
Coal-fired autogenerators	Chromium	kg	220	410
Coal-fired autogenerators	Copper	kg	290	2700
Coal-fired autogenerators	Lead	kg	380	8500
Coal-fired autogenerators	Mercury	kg	20	410
Coal-fired autogenerators	Nickel	kg	230	8100
Coal-fired autogenerators	Selenium	kg	310	1800
Coal-fired autogenerators	Vanadium	kg	170	7700
Coal-fired autogenerators	Zinc	kg	770	26000
Coal-fired autogenerators	Manganese	kg	270	16000
Coal-fired autogenerators	Beryllium	kg	15	450
Coal-fired autogenerators	PM_{10}	tonnes	100	4000
Coal-fired autogenerators	Dioxins	g ITEQ	0.89	0.29
Coal-fired autogenerators	HCl	tonnes	930	3800
Coal-fired autogenerators	HF	tonnes	110	150
Foundries	Arsenic	kg	240	28
Foundries	Cadmium	kg	140	78
Foundries	Chromium	kg	3200	100
Foundries	Copper	kg	4200	690
Foundries	Lead	kg	7600	660
Foundries	Mercury	kg	550	210
Foundries	Nickel	kg	1200	45
Foundries	Selenium	kg	24	69
Foundries	Vanadium	kg	30	69
Foundries	Zinc	kg	14000	450
Foundries	Manganese	kg	1000	-
Foundries	Tin	kg	51	-
Foundries	Dioxins	g ITEQ	2.0	2.9
Copper wire rod plant	CO	tonnes	590	-
Clinical waste incineration	Arsenic	kg	51	2.3
Clinical waste incineration	Nickel	kg	350	5.5
Clinical waste incineration	Dioxins	g ITEQ	0.53	24
Sewage sludge incineration	NO_x	tonnes	220	33
Sewage sludge incineration	Arsenic	kg	62	0.94
Sewage sludge incineration	Cadmium	kg	46	18
Sewage sludge incineration	Lead	kg	50	24
Sewage sludge incineration	Mercury	kg	72	7.4
Sewage sludge incineration	Dioxins	g ITEQ	0.062	0.48
Petrol terminals (storage)	Benzene	tonnes	6.1	19
Petrol stations (petrol delivery)	VOC	tonnes	6100	4100
Petrol stations (petrol delivery)	Benzene	tonnes	10	22
Petrol stations (petrol delivery)	1,3-butadiene	tonnes	1.2	0.79
Petrol stations (vehicle refuelling)	VOC	tonnes	37000	36000
Petrol stations (vehicle refuelling)	Benzene	tonnes	63	190
Petrol stations (vehicle refuelling)	1,3-butadiene	tonnes	7.2	6.9
Petrol terminals (tanker loading)	VOC	tonnes	750	1100

Table 2.1 Changes in emission estimates resulting from Task 1 (Year 2).

Source	Pollutant	Units	Emission	
			2002	**2001**
Petrol terminals (tanker loading)	Benzene	tonnes	1.3	5.8
Petrol terminals (tanker loading)	1,3-butadiene	tonnes	0.15	0.21
Petrol stations (storage tanks)	Benzene	tonnes	5.9	18
Petrol stations (spillages)	Benzene	tonnes	4.0	12
Fireworks	Copper	kg	2800	-
Fireworks	Magnesium	tonnes	73	-
Fireworks	Potassium	tonnes	100	-
Fireworks	Sodium	tonnes	5.5	-
Waste oil burners	SO_2	tonnes	3600	890
Waste oil burners	HCl	tonnes	62	-
Waste oil burners	Cadmium	kg	81	210
Waste oil burners	Chromium	kg	480	6200
Waste oil burners	Copper	kg	4200	4.1
Waste oil burners	Lead	kg	18000	64
Waste oil burners	Mercury	kg	42	0.032
Waste oil burners	Nickel	kg	560	3500
Waste oil burners	Vanadium	kg	980	16
Waste oil burners	Zinc	kg	27000	4.1
Waste oil burners	Manganese	kg	680	880
Waste oil burners	Tin	kg	380	-
Waste oil burners	Calcium	tonnes	440	-
Waste oil burners	Magnesium	tonnes	45	-
Waste oil burners	Potassium	tonnes	18	-
Waste oil burners	Sodium	tonnes	18	-

Note : Where a '-' is used in the 2001 data, the 2001 NAEI included no data for this activity. In the 2002 inventory, a '-' signifies that the information obtained in this programme indicates that a pollutant emission associated with an activity is trivial, or unlikely, and consequently the emission has been removed from the inventory.

Table 2.2 shows the net change in national totals for selected pollutants as a result of these changes.

Table 2.2. Change in national totals as a result of Task 1

Pollutant	% change	Pollutant	% change
Copper	+37.8%	Hydrogen chloride	-3.3%
Selenium	+24.1%	Chromium	+2.9%
Arsenic	-16.6%	Beryllium	-2.6%
Magnesium	+10.9%	Zinc	+2.4%
Lead	+9.5%	Vanadium	-2.2%
Dioxins	-6.9%	Sodium	+1.8%
Hydrogen fluoride	+6.5%	PM_{10}	-1.8%
Nickel	-6.4%	Benzene	-1.1%
Potassium	+5.4%	VOC	-1.0%
Calcium	+5.2%	Tin	+0.5%
Manganese	-4.7%	Mercury	+0.5%
Cadmium	-4.3%	SO_2	+0.2%

Table 2.2 shows that the work carried out under task 1 has sometimes had considerable impact on the NAEI although emissions of NOx, CO and 1,3-butadiene changed by less than 0.1%. It is worth noting that the research carried out under Task 1 consisted of a series of simple actions such as contacting industrial process operators. Given that each of these actions generally took only a matter of minutes to carry out, even the small changes in the VOC, benzene and PM_{10} inventories are significant. Generally, Task 1 has led to increased accuracy of the inventory (e.g. changes in metal emissions from glass including removal of emissions of certain metals), and has improved the completeness of the inventory (e.g. by adding emissions for certain metals from waste oil burners and foundries).

The revisions to the metals inventories have generally been the most significant in terms of percentage changes to the national emission totals (see Table 2.2). This may reflect the fact that the metals inventories are more uncertain than those for VOC and SO_2 (for example). The revisions to the estimates for VOC and PM_{10}, although less significant in percentage terms, are still important especially given the need to monitor UK progress towards meeting national and international obligations such as emission ceilings and exposure limits.

3 International Collaboration

3.1 NETHERLANDS/UK BILATERAL MEETINGS

Mike Woodfield attended meetings in April 2003 and January 2004 ; reports were submitted to Defra on both occasions. These periodic bilateral meetings were instigated, under this programme, to: share information on inventory development, co-operate on research where possible, and explore possibilities for joint action at international level.

The scope of the meetings has now grown and is formally led, for the UK, by the Environment Agency; AEA Technology now provides input on behalf of both the EPG 1/3/195 work and the broader NAEI programme.

3.2 SUPPORT TO THE TFEIP

Robert Stewart attended the EMEP Task Force on Emission Inventories and Projections (TFEIP), 22nd – 24th September, as the UK delegate in order to contribute to the development of the EMEP emissions and projection reporting process. His participation was independent of AEA Technology involvement as secretariat and Chair under contract EPG 1/3/162.

Mike Woodfield contributed to the formulation of the joint EU/EMEP inventory improvement programme jointly led by Sweden on behalf of the TFEIP, the Joint Research Centre (JRC), and the European Environment Agency EEA – via its topic centre on air and climate change (ETC/ACC).

3.3 COOPERATION WITH EU INSTITUTIONS

3.3.1 Joint Research Centre

Mike Woodfield visited the JRC, Ispra, on 3 occasions: 30th June 2004, 27th Nov 2004, and 2nd March 2004, partially funded under EPG 1/3/195. The purposes of the meetings variously included: assisting in the formulation of the JRC contribution to the EU/EMEP Inventory Improvement Programme referred to above, formulating guidance on inventory uncertainty best practice, providing training – based on UK experience – to acceding countries, and cooperation on the development of estimation methods for emissions from small combustion units (as part of Task 8c reported separately).

3.3.2 European Environment Agency

Mike Woodfield participated in a workshop held at Culham 14-15th May 2003 to refine the procedures for the trial review of the 2003 EMEP and NEC data submissions. The results of this programme, shortly to be published as an EEA Technical report, underpin the EMEP/EU inventory improvement programme. Similarly they will provide the targeting mechanism for the JRC emission factor development work.

3.3.3 UNECE Expert Group on Techno-economic Issues

Mike Woodfield represented UK interest at the Egtei meetings of the 3rd and 4th April, and the 9-10th October 2003. This group is a source of information to the LRTAP Working

Group on Strategies and Review. In particular it aims to provide a source of reference on new technologies, their likely emission characteristics, penetration rate, and likely costs of operation. Consequently Egtei is a useful source of core information to the NAEI and a useful forum for the exchange of inventory-related information.

4 Combustion calculator

4.1 BACKGROUND

The Year One task to review emission data for small-scale combustion (Task 7) recommended that further work be undertaken to provide a means whereby the contributions to emissions from this wide-ranging source sector could be characterised more fully within the constraints of the NAEI classification codes.

A spreadsheet calculation tool was developed to improve the emissions estimation methodology for industrial combustion appliances and smaller combustion appliances. The variability of performance of smaller combustion appliances is evident through the wide range of emission factors determined in studies around the world for combustion of fossil fuels, particularly for pollutants such as CO, PM_{10}, PAHs and PCDD/Fs.

To improve the accuracy of emission estimates within the NAEI, this Task was commissioned to investigate the most suitable emission factors for the sub-50MW_{th} sector, including consideration of boilers, furnaces and CHP plant using fuels such as coal, coke, gas oil, fuel oil, burning oil and natural gas.

The outcome of Task 8A has been a tool – Calculator (V8) – that enables the NAEI inventory team to take national fuel use statistics and apply emission factors applicable to small combustion processes, providing more representative emission estimates than previously possible.

The calculator estimates emissions of NOx, CO, PM_{10} , B[a]P and PCDD/F for the NAEI categories 'agriculture', auto-generators', 'collieries', 'gas production', 'iron & steel (combustion)', 'miscellaneous', 'other industry', 'public services', and 'railways'. It does so by taking the most detailed fuel use data from Digest of UK Energy Statistics (DUKES), further subdividing it into five size bands, and then applying appropriate emission factors for each size band. The resulting emissions are then aggregated back to NAEI categories and aggregate emission factors calculated for use in the national database.

4.2 IMPACT ON INVENTORY QUALITY

The calculator represents an improvement over the existing NAEI methodology for a number of reasons:

1) It allows emission factors to be applied to more tightly defined groups of plant, thus making it easier to select the most appropriate emission factors to use.

2) It has highlighted limitations in the DUKES data - for example development of the calculator indicates that DUKES data for fuel oil consumption in 2000 may be underestimates.

3) It provides more detailed estimates of emissions from the combustion sector than are given in the NAEI now. These more detailed estimates might be desirable for cost effectiveness studies or might assist the process of improving emissions maps.

4) It allows us to use data reported in the Pollution Inventory for NO_x emissions as part of the process of generating national emission estimates. NO_x emissions have been reported for large combustion plant since 1990 but emissions from other plant have not been easy to disaggregate and have not been reported previously.

5) The calculator can provide decision makers with more details of which sectors/processes are particularly significant sources of pollution.

6) It allows us to remove a number of double counts in the current NAEI. These double counts are not considered to be significant in terms of total UK emissions but any instance of double counting will increase the uncertainty of the inventory. The double counting occurs with combustion processes with contact i.e. brickworks, glass furnaces, metal processes where we estimate emissions of PM_{10} and some POPs from these processes but also include some emissions in our estimates for other industry fuel use so the latter contain the double counting. Because the calculator breaks fuel use down to a greater level of detail it is possible to remove these sectors from the emission estimates.

4.3 FUTURE WORK

A number of work items are recommended that would further improve the utility of the calculator. In addition, opportunities have been identified for using the calculator to explore the emission control options for small combustion plant where their use is believed to adversely influence air quality.

5 Other VOCs

5.1 BACKGROUND

This task aimed to improve the estimate of VOC emissions from the 'other solvent use' sector. This sector is intended to cover uses of organic solvents which are not included in other parts of the inventory. The objectives of the research were to identify as many solvent-using sectors as possible, and to estimate their consumption and emissions of solvent. As a result, recommendations could then be made for a new methodology for estimating emissions from the 'other solvent use' source sector.

5.2 FINDINGS AND RECOMMENDATIONS

Work is on-going due to the need to wait for important data being collected by the Solvents Industry Association (SIA). The SIA has undertaken to supply detailed estimates of solvent consumption by end-use, and these data will be an important input for this research. Research has meanwhile examined the possibility of solvents being used in the following sectors:

- oil refineries;
- oil and gas exploration and production
- plastics manufacture;
- foam production;
- retreads manufacture;
- food manufacture;
- scent and essence production;
- industrial gases;
- pharmaceuticals;
- laboratory chemicals suppliers;
- foundries;
- dyes, glazes, and pigments;
- specialist papers e.g. carbon papers;
- metallurgical processes;
- fuel additives.

5.3 IMPACT ON INVENTORY QUALITY

Due to the delay in receiving data from SIA, it is not possible to draw firm conclusions about the impact of this task on the NAEI. However, based on discussions with the SIA and other trade associations, it seems likely that significant quantities of solvents are used for applications which would fit into the NAEI category 'other solvent use'. The initial reaction of the SIA was that the current NAEI figure of 46 ktonnes of solvent used by this category of user is a reasonable estimate.

However, it is likely that emissions will be significantly lower than consumption, because many of the solvent uses identified so far involve destruction of the solvent (e.g. firelighters, barbecue fluid, fuel additives). The most likely outcome is that emission estimates for this source will fall from the current estimate of 46 ktonnes, to a figure of perhaps less than 10 ktonnes. Whatever figure is ultimately derived, the new estimate will be of considerably higher quality than the current estimate.

6 Garden Machinery Emissions

6.1 BACKGROUND

This study focused on the emission factors and activity data for off-road mobile machinery used in the lawn and garden sector. This is an aspect of the inventory which had not been reviewed for a number of years and was considered to have a high uncertainty. It was also considered a priority area due to the potential for VOC emissions. The sector covers machinery such as lawn mowers, lawn and garden tractors, chainsaws and trimmers.

The research examined new sources of emission factors for machinery equipped with spark-ignition petrol engines (2-stroke and 4-stroke), considered to be more applicable to newer designs of equipment. It also reviewed the EU Directive 2002/88/EC which set emission limits for spark ignition engines used in non-road mobile machinery and considered the impact on emission factors for types of garden machinery used in the inventory. A new set of emission factors for different garden machinery types was developed and recommended for use in the NAEI.

The research also examined the availability of activity data for this sector which included population, hours of use per year and lifetimes of specific types of machinery. Unfortunately, potential sources of such information that were contacted were unable to provide the data required within this study.

6.2 FINDINGS AND RECOMMENDATIONS

6.2.1 Revisions to emission factors

Table 6.1 summarises the new set of emission factors proposed for the NAEI as a result of this study. Original emission factor values are retained for machinery purchased before 1995. Revised figures based on the new research are recommended for machinery sold after 1995. New emission factors are recommended for machinery meeting Stage I (2004) and Stage II (2004-2011, depending on type) limit values.

Table 6.1 Summary of revisions to NAEI emission factors

Equipment Type	Engine Type	Emission Factor (g/kWh) VOCs				NOx				CO			
		Pre-Stage I (<1995)	Pre-Stage I (>1995)	Stage I	Stage II	Pre-Stage I (<1995)	Pre-Stage I (>1995)	Stage I	Stage II	Pre-Stage I (<1995)	Pre-Stage I (>1995)	Stage I	Stage II
Trimmers/edgers/ bush cutters	2sp	300	300	161	64.5	1	1	1	1	1500	1500	603	603
Lawnmowers	2sp	355	165.4	15.4	8.2	1.02	0.7	0.7	0.7	643	658	519	519
Lawnmowers	4sp	45.1	9.2	9.2	5.5	4	4.9	4.9	2.94	871	345	345	345
Ride on (domestic)	4sp	28.7	8.8	8.8	5.3	4.02	5.4	5.4	3.24	567	316	316	316
Chain saws <4 bhp	2sp	660	660	161	64.5	1	1	1	1	1500	1500	603	603
Lawn and garden tractors	4sp	28.7	8.8	8.8	5.3	4.02	5.4	5.4	3.24	567	316	316	316
Lawn and garden tractors	2sp	270	136.9	15.4	8.2	1.05	0.6	0.6	0.6	460	460	460	460

6.2.2 UK Emission Estimates for garden machinery

Using existing activity data on population, sales and lifetime of garden machinery in the UK, national emissions of NOx, CO and NMVOCs were calculated using a) the original set of emission factors used in the NAEI; b) the new set of emission factors for machinery sold since 1995, but excluding the impact of the Directive limit values, i.e. assuming factors for all machinery remains at current levels; and c) the new set of emission factors for current machinery and including the effect of the Directives (i.e. using all the emission factors in Table 6.1).

The effect on emissions from 1995 to 2010 for each of these three cases is shown in Figures 6.1-6.3.

The new emission factors lead to a significant reduction in estimates of emissions of CO and NMVOCs from garden machinery in 2002, but little change in the estimates for NOx emissions. It can also be seen that the Directive emission limit values will lead to reductions in NOx and NMVOC emissions over the next decade, but little change in emissions of CO from garden machinery.

To put the garden machinery emissions into context, emissions of NOx are 0.06% of the UK emission totals in 2002 and are virtually unchanged using the new emission factors. For CO, use of the new emission factors decreases the emission estimate from 94 to 75 ktonnes in 2002, and compares with 3238 ktonnes from all sources, i.e. 2.3% of total emissions. For NMVOCs, use of the new factors decreases the emission estimate from 29 to 17 ktonnes in 2002, and compares with 1364 ktonnes from all sources, i.e. 1.2% of total emissions.

Fig. 6.1 Emissions of NOx from garden machinery

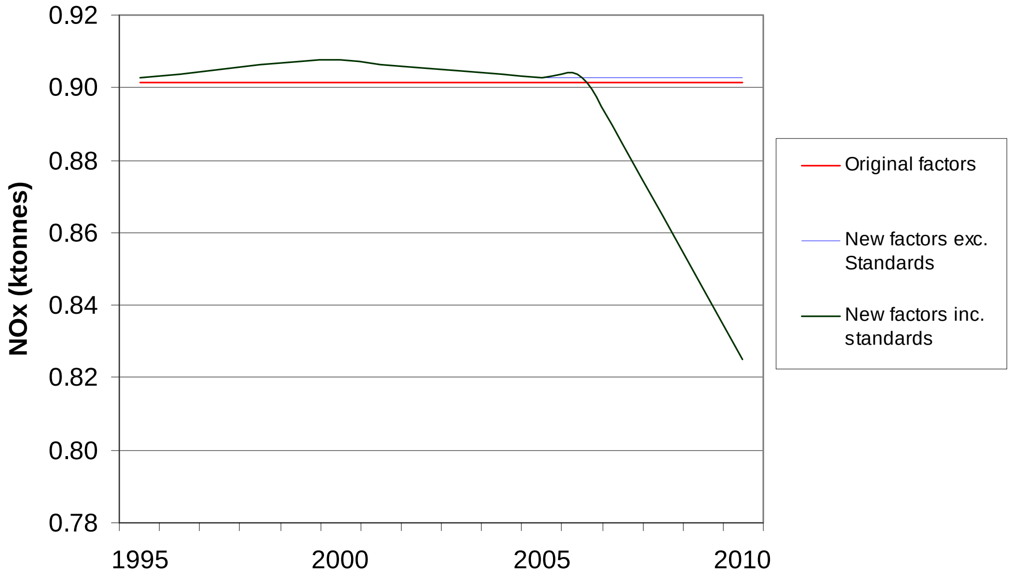


Fig. 6.2 Emissions of CO from garden machinery

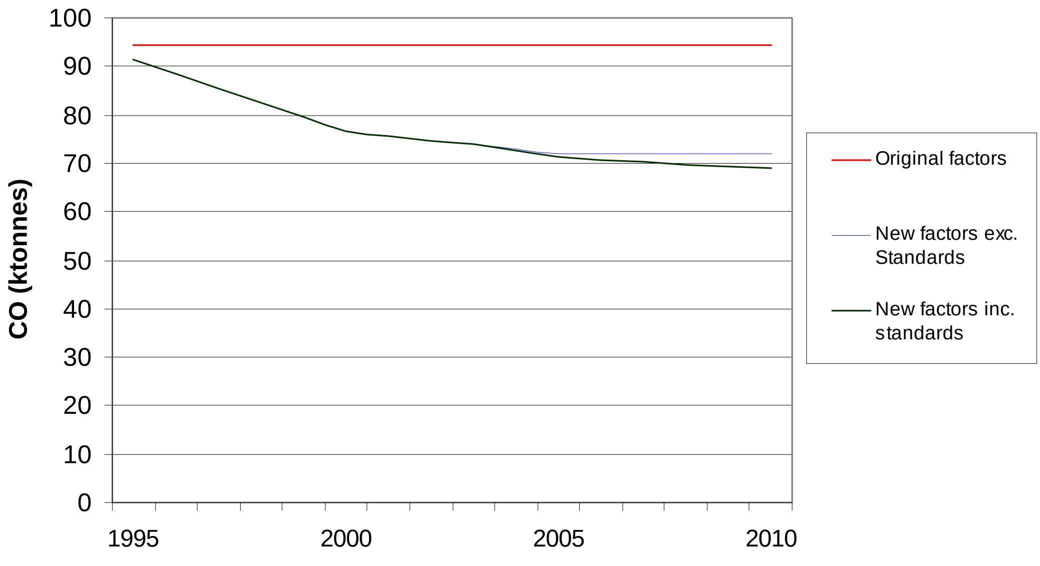
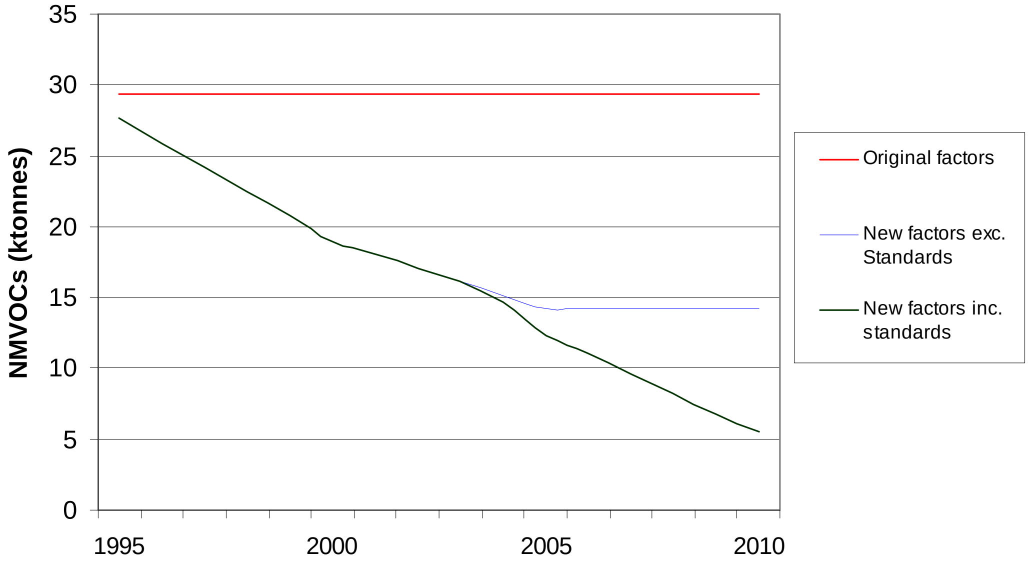


Fig. 6.3 Emissions of NMVOCs from garden machinery



6.3 IMPACT ON INVENTORY QUALITY

The impact that changing to the new set of emission factors has on emissions of NOx, NMVOCs and CO from garden machinery was calculated in the inventory model using existing activity data.

For 2002, the new emission factors leaves NO_x emissions from garden machinery almost unchanged, but leads to a decrease in CO emissions of 21% and NMVOC emissions of 42% compared with estimates using the original emission factors. Emissions of all three pollutants are projected to fall with penetration of newer, lower emitting machinery into the population when compared with previous forecasts.

The proposed revisions to the NAEI are for emission factor data, activity data are unchanged and this remains a significant source of uncertainty for the sector.

7 Industrial PM Emissions

7.1 BACKGROUND

This aim of this Task was to review emission factors and speciation profiles used in the compilation of PM_{10} (Particulate Matter smaller than nominally 10µm) and sub PM_{10} inventories for industrial and selected combustion processes of the NAEI. The emission data include operators' estimates of annual emissions of PM_{10} (to the regulatory authorities (for example the Environment Agency Pollution Inventory for England & Wales), published emission factors for PM_{10} and, size speciation profiles.

The NAEI includes emission data for PM in the following size categories :

- PM_{10} - Particulate matter less than nominally 10 µm
- $PM_{2.5}$ - Particulate matter less than nominally 2.5 µm
- $PM_{1.0}$ - Particulate matter less than nominally 1.0 µm
- $PM_{0.1}$ - Particulate matter less than nominally 0.1 µm

Inventories have been developed for a variety of sources including industrial and combustion sectors. However, the inventories for these pollutants have significant uncertainty within the NAEI.

7.2 FINDINGS AND RECOMMENDATIONS

7.2.1 PM_{10} emissions from industry in the NAEI

The review of industrial emissions of PM_{10} has highlighted several issues including the fundamental question of what is the PM_{10} when emitted from a process. In general, the NAEI includes emission estimates based on a 'filterable' PM_{10} release. However, the emission factors within the NAEI for natural gas combustion assessed in this Task also include a 'condensable' fraction.

The US Environmental Protection Agency (USEPA) defines two fractions to a PM_{10} emission from an industrial or combustion source. The filterable PM_{10} fraction in a stack emission can be determined using USEPA Method 201A and is essentially material which is smaller than nominally 10µm (separated from larger PM using a miniature cyclone) and which can be retained by a filter at stack temperature. Condensable PM is also considered to be PM_{10} and is material collected downstream of the sampling filter from probe rinses and material collected within a chilled impinger train (USEPA Method 202).

The test procedure for condensable PM (Method 202) is a promulgated test procedure and emission inventories in the US are required to consider both filterable PM_{10} and the condensable PM_{10} emissions. However, the test method has been subject to considerable debate concerning whether it provides data representative of condensable emissions. It is intended to replicate secondary formation of particulate by condensation downstream of the stack. However, although the sampling procedure lowers the temperature of the sampled gases, there is no concurrent dilution action. Interferent effects are also possible. Limited evidence from dilution tunnel experiments suggests that Method 202 may overestimate condensable emissions.

The NAEI incorporates data reported by process operators to the regulatory authorities.

The regulatory authorities require operators of selected processes to report PM_{10} emissions for inclusion in the Pollution Inventory (or EPER) above a threshold of 10 tonnes per year. This information is then incorporated into the NAEI. The methodologies adopted by process operators for estimating PM_{10} emissions includes a mixture of direct measurements, emission factors, or factors applied to a total particulate emission.

The protocol for Inventory reporting adopted by the Electricity Supply Industry Joint Environment Programme (JEP) is typical in that it applies a PM_{10} factor to the total particulate emission. The JEP protocol states that the ESI total particulate emission data for coal-fired stations are based on continuous monitoring systems. These systems do not monitor the condensable fraction. Similarly other operators may base emissions data on short-term measurements of particulate emission which almost certainly do not include assessment of the condensable fraction. Conversely, other operators may include condensable material in their reports through use of USEPA default emission factors for their process.

The scale of these inconsistencies and their impact on the NAEI is unknown. The consistency of PI/EPER reporting by process operators will be addressed in time by various initiatives including guidance from the regulatory authorities or operator initiatives such as the JEP protocol.

Hence, methodology issues result in inconsistencies in the treatment of PM_{10} within the NAEI. This Task has sought to address these for the processes assessed. The bulk of existing PM_{10} emission data in the NAEI are for ‘filterable’ PM_{10} and, there are concerns over the validity of the condensable PM test procedure. Hence to ensure consistency within the NAEI, only filterable PM_{10} data should be considered. Default PM_{10} and other PM_{10} emission factors used in the NAEI for industrial and combustion sources should be reviewed to determine if any include a condensable component.

7.2.2 Main sources

The most significant emitters in each size range for the 2002 NAEI were identified and are summarised in Table 7.1.

The sector “Other Industry – Part B process – Non fuel” is a composite of many different processes and could not be adequately examined within the scope of this task. The manufacture of cement clinker was identified as an important source and examined in more details.

Analysis of the most significant industrial emitters of PM_{10} and sub-PM_{10} indicates several common sectors within each pollutant category. These sectors include :

- ‘Coal combustion,’ and ‘Natural gas combustion’ for power generation public utility power stations or other industry subsectors,
- ‘Iron and steel sintering plants’,
- ‘manufacture of non-fletton bricks’

Each of these sectors and the manufacture of cement clinker were reviewed.

Table 7.1 The most significant industrial PM emission sources

PM fraction Ranking	NAEI Sector description	2002 Inventory ktonnes
PM 10		
1	Power stations >300MW – Coal	7.849
2	Other Industry – Part B process – Non fuel	4.551
3	Other Industry – combustion of coal	3.751
4	Brick Manufacture – Non-Fletton	2.345
5	Iron and Steel sinter plant	2.140
PM 2.5		
1	Power stations >300MW – Coal	3.453
2	Other Industry – Combustion – Coal	2.664
3	Other Industry – Part B process – Non fuel	2.276
4	Other Industry – Combustion – Natural Gas	1. 684
5	Iron and Steel sintering – Iron Production	1.605
PM 1.0		
1	Other Industry – Part B process – Non fuel	2.276
2	Other Industry – Combustion – Natural Gas	1. 684
3	Power stations >300MW – Natural Gas	1.510
4	Power stations >300MW – Coal	1.490
5	Brick Manufacture – Non-Fletton	1.384
PM 0.1		
1	Other Industry – Combustion – Natural Gas	0.842
2	Power stations >300MW – Natural Gas	0.758
3	Iron and Steel sintering – Iron Prod.	0.728
4	Other Industry – Part B process – Non fuel	0.682
5	Brick Manufacture – Non-Fletton	0.680

7.2.3 Manufacture of non-fletton bricks

The Brick manufacture industry, involves taking raw materials, usually clay or shale, and then processing them for desired additional qualities and standards before firing the end product in a kiln. Particulate can be produced at several stages during the handling, transporting and processing of these materials, including the substantial potential particulate that can be produced during the firing stage.

Annual Emissions from the processes are not currently reported to the Pollution Inventory. The 2002 NAEI PM_{10} emission is calculated from estimates of non-fletton brick production data and an emission factor sourced from USEPA data. A review of the USEPA emission factors was undertaken and indicates that a 'worst case' factor has been applied but **netcen** considers that a more appropriate PM_{10} factor can be derived (see Table 7.2).

Table 7.2 – Comparison of NAEI and proposed emission factors for non-Fletton brick manufacture

Activity	Emission factor, ktonne PM_{10} / ktonne bricks	
	NAEI 2002	**Proposed**
Primary crusher with fabric filter	-	0.000000263
Processing dry material - uncontrolled	0.000257	-
Processing dry material with fabric filter	-	0.00000143
Extrusion line with fabric filter	-	0.00000161
Natural gas-fired kiln : Filterable PM_{10}	0.000125	0.000125
Total	**0.000382**	**0.000128**

The 2002 NAEI size speciation profile is based on kiln emissions and also derived from USEPA data but no new data could be identified and consequently the size speciation profile has not been modified. The sub-PM_{10} fractions would be reduced if the proposed PM_{10} emission factor were to be adopted (Table 7.3).

Current emissions figures listed for manufacture of non-fletton bricks in the NAEI data base have been taken from the USEPA publication AP42, section 11.3-3 (August 1997). The emission figures together with the speciation profile (also taken from AP42) are further displayed in Table 7.3 below.

Table 7.3 – Sub-PM_{10} emissions for non-Fletton brick manufacture

Particulate Fraction	Speciation profile	UK Emissions (Kilotonnes)	
		NAEI 2002 emission data	Revised 2002 emission
PM_{10}	100%	2.345	0.851
$PM_{2.5}$	64%	1.501	0.545
$PM_{1.0}$	59%	1.384	0.502
$PM_{0.1}$	29%	0.680	0.238

There is lack of emission information for this industry sector and **netcen** recommends that measurements be undertaken to develop more robust size speciation data.

7.2.4 Manufacture of cement clinker

The manufacture of Portland Cement, involves heating raw material in a coal-fired kiln at temperatures up to 1500°C. A range of alternative fuels including tyres and recovered liquid fuels are also used by operators to displace use of coal.

The PM_{10} emission currently quoted in the NAEI are sourced from the operators' estimates (for example the information in the EA Pollution Inventory). The sub-PM_{10} inventories are based on particle size data derived from US EPA publication AP 42, section 11.6 dated January 1995.

The size speciation profile is considered to be still the most appropriate for the NAEI. However, the particle size data are limited (the data are only for PM_{10} and $PM_{2.5}$.) The smaller PM fractions ($PM_{1.0}$ and $PM_{0.1}$) have been extrapolated from the USEPA PM_{10} and $PM_{2.5}$ data for kiln emissions.

In the absence of other data no change is proposed to the 2002 NAEI figures. However, apart from PM_{10} there is lack of recent data for this industry sector and **netcen** recommends that measurements be undertaken to develop more robust size speciation data.

7.2.5 Combustion of coal

Table 7.1 indicates that the combustion of coal is one of the major industrial sources of particulates. Combustion of coal is one of the most significant sources of PM across several size ranges and within two source sectors, Power stations and other industry.

Particulate emissions from combustion of coal at large combustion plant have been regulated for many years. Major combustion installations provide estimates of annual PM_{10} emissions to the UK regulatory authorities.

The Other Industry sector PM_{10} emission estimates for the 2002 NAEI are based on a USEPA emission factor for stoker-fired boilers. This factor is considered to have a high uncertainty for this broad sector which includes a wide range of combustion technologies and plant size. However, the PM_{10} factor has not been considered in this task as it is addressed in Task 8a – the combustion calculator.

The current sub-PM_{10} emissions data used in the NAEI are derived from a speciation profile from the USEPA publication AP42. This provides a speciation profile for the PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ species for the combustion of coal using ESP (electrostatic precipitators) as abatement technology. Almost all major UK coal-fired power stations have ESPs for particulate abatement, two stations also have Flue Gas Desulphurisation scrubbers and one station (currently in receivership) which has fabric filters. Other Industry sources include a range of abatement techniques however. In the absence of other data the NAEI speciation profile is based on the same USEPA data as for power stations.

The fraction of $PM_{0.1}$ has been extrapolated from the USEPA speciation profile. No newer or more relevant data were obtained consequently no change is proposed for the speciation data used by the NAEI database.

However, the USEPA speciation profiles are dated, are for non-uk plant (and fuel) and, there is no imminent requirement for plant operators to determine sub-PM_{10} particle sizes. Consequently, it is recommended that measurements are undertaken to obtain more appropriate data and assess the uncertainty of emissions associated with these sectors.

7.2.6 Iron and steel – sintering plants

The manufacture of iron and steel is a complex process requiring several key operations in succession to produce an end product. Sinter production is one of the key stages in this process. Iron ore, coke, limestone, mill scale and flue dust are mixed and roasted and ignited under gas burners to produce 'sinter'. This product is then passed to the blast furnace. Flue gases are passed through an electrostatic precipitator to remove PM before being released to atmosphere.

The PM_{10} emissions data in the NAEI database have been compiled from operators' data (information supplied to the Pollution Inventory). The sub-PM_{10} size fractions are derived by applying a speciation profile to the PM_{10} data. The speciation profile is from the USEPA AP-42 data but refers to data published in October 1986.

A more recent speciation profile has been sourced from the European IPPC bureau Best Available Technology Reference Note (BREF) for Iron and Steel production. Table 7.4 compares the 2002 NAEI data and speciation profile with the proposed speciation profile and revised emission.

Table 7.4 - Speciation profiles and UK emissions for sinter plants

NAEI speciation profile		NAEI 2002 UK Emissions, ktonne	Proposed speciation profile		Revised 2002 Emissions, ktonnes	% Change
PM_{10}	100%	2.140	PM_{10}	100%	2.140	0
$PM_{2.5}$	75%	1.605	$PM_{2.5}$	84%	1.798	+12
$PM_{1.0}$	50%	1.070	$PM_{1.0}$	66%	1.412	+32
$PM_{0.1}$	34%	0.728	$PM_{0.1}$	9%	0.193	-74

7.2.7 Combustion of natural gas

Natural gas is a key fuel for industry and power generation. The combustion of natural gas appears in the highest five emitters of particulates for several PM fractions. This is perhaps surprising given the inherent low potential for particulate emission from combustion of refined gas. The scale of gas use is increasing and the significance of the sector is increasing as other sources decline. The emission of PM from combustion of natural gas is also significant for the 'other industry' sector.

At present, the UK Electricity Supply Industry JEP inventory reporting protocol reports PM_{10} emissions from gas combustion as zero or operators report emissions below the reporting threshold (10 tonnes per year). Consequently, the data used to calculate the UK emissions of PM from combustion of natural gas within the NAEI, comes from a literature value.

For the electricity supply industry the NAEI default emission factor is currently **154 kg/Mtherm** however, the source of this factor is unclear. The default factor is about half the USEPA emission factor for total PM (filterable and condensable PM) which is currently used for the 'other industry' and other gas combustion sectors within the NAEI (**338 kg/Mtherm**).

This review indicates that the USEPA emission factor for filterable PM from combustion of natural gas (**84 kg/Mtherm**) should be used by the NAEI in all sectors. Measurement of filterable PM_{10} at a power station gas turbines for Defra and a smaller gas turbine for the EA and, data for gas combustion published by EMEP, indicate PM_{10} emission factors of similar order to the default USEPA factor. However, it should be noted that these emission measurements are likely to have a high uncertainty.

The proposed emission factor is approximately half that of the current 'default' factor used for electricity generation but is traceable and is consistent with PM_{10} emissions from combustion in other areas of the NAEI (that is it is consistent with the PM_{10} emissions from other sources reported to the Pollution Inventory).

The USEPA states that the particulate produced by combustion of natural gas is assumed to be the same for **all** natural gas combustion and is effectively $PM_{1.0}$. Therefore the value for PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ will be the same. The USEPA data does not include speciation data for the $PM_{0.1}$ fraction. Currently within the NAEI 2002 database, the $PM_{0.1}$ fraction is half the value stated for $PM_{1.0}$. No new information has been found to justify modifying the speciation profile for gas combustion.

Table 7.5 – Gas combustion PM emissions

PM size fraction		Power station, emissions ktonnes		% Change	Other Industry emission, ktonnes		% Change
		NAEI 2002	Proposed 2002		NAEI 2002	Proposed 2002	
PM_{10} , $PM_{2.5}$ $PM_{1.0}$	100%	1.516	0.826	-46	1.684	0.434	-74
$PM_{0.1}$	50%	0.758	0.413	-46	0.842	0.217	-74

There is lack of data for gas combustion and available data indicate comparatively high emissions of PM_{10} from gas combustion. **netcen** recommends that measurements be undertaken to develop more robust PM_{10} and size speciation data for gas combustion.

8 Summary of Project Reports

Details of the project reports and other deliverables are summarised below.

Item	Task	Details
Task Report	Task 1 Simple desk-based studies	AEAT/ENV/R/1715
Task Report	Task 8a – Combustion calculator Task 8b – Other VOC Task 8c – Garden Machinery	AEAT/ENV/R/1712 In preparation AEAT/ENV/R/1719
Task Report	Task 9 – PM Emissions from industrial sources	AEAT/ENV/R/1714
Annual summary report	Annual report	AEAT/ENV/R/1716

A report for the Task 8b (Other VOCs) will be prepared on completion of the task.