Report

Emission factors programme Task 7 – Review of Residential & Small-Scale Commercial Combustion Sources

Report to the Department for Environment, Food and Rural Affairs; the National Assembly of Wales: the Scottish Executive; and the Department of Environment in Northern Ireland

Report

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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) 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 that 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.

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 quality are the transparency, completeness, consistency, comparability and accuracy of the data within the inventory.

This report details the findings of a desk-based study into the quality of emission factors pertaining to small-scale combustion units, with the aim of improving the confidence that an inventory user may place in the estimate of the mean emission factors within the NAEI for this range of activity.

The improvement of the inventory data for this sector has been driven according to the five key aspects of inventory data quality :-

Transparency – assessment of data suitability to the activity sector, investigating and summarising the assumptions and measurement methodologies upon which the source data are based.

Completeness – a review of the small-scale combustion sector and the relevant inventory data has identified where specific activities may have been overlooked or where the emission factors have not been focussed closely upon the activity type.

Consistency – Regarding the consistency of inventory data compared to data from previous years, the cross-checking of data from a range of information sources provides a simple insight into the likely accuracy of emission factors

pertinent to the small-scale combustion sector. The technical review of information sources goes some way to ensuring that the asumptions and measurement methods used to generate emission factors are based on consistent criteria.

Comparability – The study has involved comparison of NAEI data with other international inventories such as the AP-42 factors used by the US EPA, EMEP-CORINAIR data, RAINS model and other European inventories. The NAEI is already designed to utilise consistent standardised formats and assessment methodologies, and this study has continued to maintain this approach.

Accuracy – The inherent uncertainties in any emission factor must be assessed to allow a reasoned judgement of the usefulness of the data. The small-scale combustion sector has been identified as an area that requires further investigation because of the perceived uncertainties in historic NAEI data. This study has sourced many new research reports that have been specifically tailored to developing a better understanding of the values and variability of emission factors for small-scale combustion. By assessing these reports, some improvements to specific emission factors have been recommended. In addition, key areas have been identified that may require further research to improve accuracy of emission factors.

From the data collected, changes are recommended for emission factors applied to the following sub-sectors of the NAEI small-scale combustion sector :

- about 70% of the NO_x , VOC, CO, PM_{10} , Benz(a)pyrene and dioxins emission factors currently applied for six solid fuels in domestic combustion

- the PM_{10} and CO emissions for domestic combustion of natural gas

- about 80% of the NO_x , VOC, CO, PM_{10} , Benz(a)pyrene and dioxins emission factors currently applied for burning oil in domestic combustion

- about 70% of the NO_x , VOC, CO, PM_{10} , Benz(a)pyrene and dioxins emission factors currently applied for fuel oil use across four consumption sectors.

The following sub-sectors of the small-scale combustion sector are recommended for further technical investigation to improve NAEI emission factor data:-

- Burning Oil (kerosene) consumption in domestic boilers and industrial space heating appliances
- Natural gas consumption in the different generic designs of CHP plant
- Gas oil combustion in the agricultural, public and commercial sectors
- Domestic and public and commercial combustion of LPG
- Domestic combustion of wood

In addition, the following sources of uncertainty in NAEI data warrant further investigation:-

- **Activity data** – Significant disparity in UK coal consumption is evident between DTI-sourced data and industry-sourced figures. There may be an end-user group as yet unrepresented, or at least mis-represented, within the current NAEI data.

- **Domestic split between open fires, closed stoves and boilers** – progress has been made in identifying the trends regarding solid fuel use in different types of domestic appliance. The different appliances exhibit significantly different combustion profiles, and hence the assessment of the relative uses of the range of household appliances (broadly divided into: fireplaces, stoves and boilers) could be a significant source of error in the use of NAEI data. Annual estimates for these sub-sectors of activity data are therefore recommended to provide a mechanism to calculate a more accurate emission factor that is more representative of the whole of the domestic sector for each fuel.

A potential source of emission data research on small-scale combustion (and other sources) is via the national programmes of other countries and co-operative international emission inventory work programmes at UN ECE or EU level. Emissions from residential and other small-scale combustion sources are a common area of concern; it is known that work is being undertaken in several EU member States and the EC's Joint Research Centre, Emissions and Health Unit, has in place a work programme to co-ordinate this activity and encourage the exchange of information.

However, emission data from sources outside the UK are of little use to development of the NAEI if the source measurements are for combustion technologies or fuels which are not employed in the UK. To improve inventory uncertainty emission data should, wherever possible, be obtained from accredited test houses using recognised test protocols (for example EN or ISO Standards).

Contents

1 Introduction

1.1 EMISSION FACTORS PROGRAMME

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1.2 EMISSIONS FROM SMALL COMBUSTION SOURCES

Enquiry has shown that research into emissions from smaller combustion sources is few and far between, and those reports that have been generated commonly demonstrate significant variability in the emissions from a given source. There is a resultant lack of comparability of the procedures and it is unlikely that the accuracy of the current emission factors is high. As a result, the error margins for

emission factors applicable to smaller combustion sources are considered to be much greater than those for larger combustion sources.

In addition, the application of combustion control and emission abatement technologies is not prevalent across smaller combustion units, due to economic and practical considerations. Domestic fireplaces, stoves and poorly maintained central heating units are also prone to poor combustion of fuel. Across this sector, therefore, significant emissions of pollutants such as Particulate Matter less than nominally 10µm (PM_{10}), carbon monoxide (CO) and organic species such as dioxins and furans and Polycyclic Aromatic Hydrocarbons (PAHs) may be produced.

This report summarises the findings of research into the small-scale combustion sector in the UK, drawing upon relevant emission factor research across the world and identifying fuel consumption data, technological changes and market trends pertinent to the UK. To help to define the scope of this research project, the term “Small-scale combustion plant” pertains to a unit of less than 20 MW net thermal input, as this is the threshold for a UK combustion facility to fall under local authority regulation.

1.3 REPORT STRUCTURE

In addition to providing guidance on the development of emission factors and furthering knowledge of this sector as a whole, this report identifies the key aspects of this section of the NAEI that require further investigation.
The report is structured as follows:-

Section 2: Methodology
Outlines the sources and methodology employed during this study.

Section 3: Description of Small-Scale Combustion Sector
Includes a breakdown of fuel combustion across sub-sectors, a summary of target pollutants relevant to each sub-sector and an outline of trends in fuel consumption.

Section 4: Coal
Summary of sources and emission factors for coal use across all small-scale combustion sub-sectors.

Section 5: Coke and Manufactured Solid Fuels
Summary of sources and emission factors for coke use and manufactured solid fuel use across all small-scale combustion sub-sectors.

Section 6: Wood and Biomass
Summary of sources and emission factors for wood and biomass use across all small-scale combustion sub-sectors.

Section 7: Petroleum-Based Oils and Gases
Summary of sources and emission factors for the use of LPG, burning oil and fuel oil across all small-scale combustion sub-sectors.

Section 8: Natural Gas
Summary of sources and emission factors for the use of natural gas across all small-scale combustion sub-sectors.

Section 9: Conclusions and Recommendations
Summary of key findings and recommended future work.

Section 10: References
Details of source documents. Within the main text, references are usually indicated thus: [Reference No.].

Appendix A provides a summary of the UK energy consumption statistics for 2001.

Appendix B lists the emission factors determined for each fuel and combustion source.

Appendix C summarises and compares the combustion emission factors by fuel and combustion sector.

2 Methodology

The annual review of NAEI data has identified the need to understand and control the uncertainty in the emission factors used for small-scale combustion sector across a range of pollutants. For several fuel and pollutant combinations only a single emission factor was evident for a pollutant across the whole range of small-scale combustion sources.

Hence a desk-based study was commissioned to collate and review data and background information across two broad areas:-

1) Emissions of pollutants from a range of different types of small-scale combustion device, incorporating inputs for different fuels where possible, to include: coal, coke, smokeless solid fuels, wood, oil & gas.
2) The market share of individual types of small-scale combustion device and fuel type within the UK.

The combination of these two information types provided a cost-effective way of developing reasoned assumptions for the simplification of an otherwise prohibitively complex task.

Literature searches of relevant journals and web-based resources were conducted to find current estimates of emission factors for the following pollutants:

- Carbon monoxide (CO)
- Nitrogen Oxides (NO_x)
- Particulate matter less than nominally 10µm (PM_{10})
- Dioxins
- Polycyclic aromatic hydrocarbons (PAH)

Several sources included figures for other species such as SO_2, benzene, PCBs, PCNs, and these have been recorded where appropriate. Note that for SO_2 in particular, the emission factors from combustion sources are dependent primarily on the sulphur content of the fuel.

Key sources of information included:-

- the US EPA Compilation of Emission Factors for Air Pollutants, Fifth Edition (AP-42)
- the EMEP / CORINAIR Emission Inventory Guidebook, 3rd edition (2001)
- UK-based research reports conducted by energy-focused organisations such as CPL Laboratories & the Coal Research Establishment.
- Studies conducted to demonstrate the compliance of a given combustion unit with the requirements of the UK Clean Air Act
- Review of the UK Domestic Heating Market (2001)

Research into the trends and current numbers, capacities and range of fuels & technologies across the small-scale combustion sector in the UK was conducted via web-based resources, Government publications and consultation with industry bodies and individual companies.

The data collated was assessed for its relevance to the UK emissions inventory, and technical emissions reports were reviewed by experts in emission monitoring to enable a critical appraisal of the source monitoring techniques employed and therefore a measure of the reliability of the emission factors derived.
This study has aimed to achieve the following steps towards improvement of the NAEI data for the small-scale combustion sector:-

- Identify the range of commonly used combustion appliances across the different sub-sectors of the UK small-scale combustion market.
- Improvement of the estimation of fuel use allocation across the different combustion appliances identified, to enable more accurate distribution of DUKES annual UK fuel use data within the sector.
- Identify the fuel/appliance combinations, by pollutant, which most influence the uncertainty of the 'aggregate' emission factors used in the inventory and focus the study in these areas.
- Examine the adequacy of available data for each of the different sub-sectors of the UK small-scale combustion market.

The areas most in need of accurate data to enable a representative assessment of the UK situation have been identified and default factors derived to compare and contrast against those used at present within the NAEI.

3 Small-Scale Combustion Sector

3.1 DESCRIPTION OF SECTOR

Small combustion processes include those from residential, commercial, public and agricultural combustion sources. The sub-20 MW combustion sector in the UK can be broadly divided into the following sub-sectors [1]:-

- Domestic fireplaces & stoves
- Domestic central-heating systems
- Small commercial & institutional boilers
- Agricultural heating systems
- Industrial space heating systems
- Combined Heat & Power (CHP) installations

Each of these sub-sectors exhibits its own variation in fuel sources and combustion appliances, although many of the emission factors developed for combustion in one sub-sector will be applicable to others.

A common feature of smaller-scale combustion devices is the release of significant quantities of Products of Incomplete Combustion (PICs) such as CO, unburned hydrocarbons, particles, tar and PAHs. The incomplete combustion is mainly caused by a combination of the following:-

- Low combustion temperatures
- Short residence times
- Poor mixing due to insufficient turbulence
- Oxygen shortage

Historically, technology to reduce such emissions is infrequently used in residential fireplaces and stoves due to economic & practical constraints. Small commercial boilers and larger combustion units do exhibit some flue gas treatment technologies, with the improvement of combustion control being the primary mechanism.

3.2 CONTRIBUTION TO TOTAL UK EMISSIONS

Despite the relatively low fuel throughput of the small-scale combustion sector, (compared to larger industry & power generation, for example) the poor combustion efficiency of appliances within the sector and their use in centres of population ensures that it can make a significant contribution to total UK emissions of pollutants and, can often have a high local impact. The table below illustrates the scale of the contribution of the small-scale combustion sector to total EC emissions of target pollutants, as calculated by the International Institute for Applied Systems Analysis (IIASA) using the Regional Air pollution Information and Simulation (RAINS) emission inventory model [2].

Pollutant	Small-scale combustion contribution to total EC emissions of target pollutants		
	1990	1995	2010 prediction
NO_X	4 %	4 %	7 %
SO_2	10 %	10 %	11 %
NM VOC	7 %	7 %	7 %
PM_{10}	33 %	34 %	36 %

[Source: IIASA, 2002]

3.3 FUEL CONSUMPTION AND TRENDS

3.3.1 Digest of UK energy statistics

The information in this section has been sourced from the 2002 Digest of UK Energy Statistics (DUKES [3]) and consultations with trade organisations and individual companies, including the Solid Fuel Association and HETAS Ltd.

A summary of fuel consumption across the smaller combustion sectors is given below, taken from the DUKES 2002 statistics:-

Fuel	Domestic	Public	Commercial*	Agriculture	Misc.
Steam Coal, tonnes (*GWh*)	1,428,000 (*12,100*)	126, 000 (*1070*)	6000 (*51*)	5000 (*43*)	10,000 (*86*)
Anthracite, tonnes (*GWh*)	1,110,000 (*9,100*)	-	-	-	-
Manufactured solid fuels, tonnes (*GWh*)	513,000 (*4070*)	-	-	-	-
Wood, Tonnes oil equiv. (*GWh*)	204,000 (*2370*)	-	-	-	-
Renewables, Tonnes oil equiv. (*GWh*)	-	49,000 (*570*)	71,000 (*826*)	72,000 (*837*)	-
Propane, tonnes (*GWh*)	253,000 (*3510*)	-	575,000 (*7990*)	109,000 (*1510*)	-
Butane, tonnes (*GWh*)	64,000 (*880*)	-	124,000 (*1700*)	1000 (*14*)	-
Burning oil, tonnes (*GWh*)	2,648,000 (*35,000*)	12,000 (*160*)	1,561,000 (*20,600*)	12,000 (*160*)	-
Gas Oil, tonnes (*GWh*)	193,000 (*2400*)	674,000 (*8300*)	402,000 (*5000*)	448,000 (*5500*)	109,000 (*1350*)
Fuel Oil, tonnes (*GWh*)	6000 (*70*)	40,000 (*480*)	34,000 (*400*)	11,000 (*130*)	18,000 (*210*)
Natural Gas (*GWh*)	(*379,200*)	(*45,500*)	(*36,500*)	(*1300*)	(*28,200*)

*Commercial figures include some general industry space heating figures for propane, butane and burning oil.

Summary tables by sector and by total energy consumption are included in Appendix A, to illustrate the distribution of fuel use across the sub-sectors. Further details for each fuel type are outlined in the following sections.

3.3.2 Solid Fuel Consumption

The DUKES figures for solid fuel consumption in 2001 indicate that 2.5 million tonnes of coal were consumed in the domestic sector. Figures provided by the Solid Fuel Association (SFA), however, suggest that total domestic consumption of solid fuels in 2001 totalled only 1.6 million tonnes, with steam coal comprising just under 50% of this amount [4]. This discrepancy may indicate that there is a category of end-user that is not represented accurately (or at all) within the NAEI data, and this element of activity data uncertainty needs some further investigation.

The SFA predictions for 2003 consumption total 1.2 million tonnes of solid fuel, which represents a 25% reduction over only 2 years, reflecting the trend towards use of gas and oil and away from solid fuel.

Further to this data, the SFA also commented that sales of domestic combustion appliances have remained buoyant in recent years, with multifuel appliances dominating the market. These types of appliance are typically used for secondary heating and occasional use. Only a limited number of appliance are commercially available that can burn wood or coal smokelessly.

3.3.3 Petroleum-Based Oils and Gases

The DUKES data presents petroleum products including a number of different fuel oil and gas grades that are used across the small combustion sector.

Propane – used mainly for industrial purposes and some domestic heating. Normally stored and transported in pressurised liquid form. The proportions of total propane consumption are as follows:-

Domestic heating and cooking:	27 %
Small commercial & industrial boilers:	61 %
Agricultural heating:	12 %

Butane – used mainly for industrial purposes and some domestic heating. Normally stored and transported in pressurised liquid form. The proportions of total butane consumption are as follows:-

Domestic heating and cooking:	34 %
Small commercial & industrial boilers:	66 %
Agricultural heating:	1 %

Burning Oil (kerosene) – Refined petroleum fuel, intermediate in volatility between motor spirit and gas oil. Used almost entirely for heating and lighting in

the domestic and industrial sectors. The proportions of total burning oil consumption are as follows:-

Domestic heating and cooking:	63 %
Small commercial & industrial boilers:	37 %

Gas Oil (Diesel Oil) – Petroleum fuel with a distillation range between kerosene and fuel oil. Used predominantly as a burner fuel in heating installations and for industrial gas turbines. The proportions of total gas oil consumption are as follows:-

Domestic heating and cooking:	11 %
Small commercial & industrial boilers:	59 %
Agricultural power, drying & heating:	25 %
(Miscellaneous central heating):	17 %

Fuel Oil – heavy petroleum residue blend used in atomising burners and for heavy duty diesel engines. The proportions of total fuel oil blend consumption are as follows:-

Domestic heating and cooking:	5 %
Small commercial & industrial boilers:	68 %
Agricultural power, drying & heating:	10 %

Trends in Oil Consumption, 1999-2001

In the **domestic** sector, the key petroleum-based fuel is Burning Oil, and consumption of this fuel increased by 11% during these two years. Of the other fuels that are commonly used in the domestic sector, there seems to have been a shift from use of butane (down by 60% in 2 years) towards the use of propane (up by 82% over 2 years).

In the **small commercial & public** sector, the main fuel for heating and boilers has historically been gas oil, with fuel oil the only other significant fuel source. However, both of these have been exhibiting declines in consumption in this sector, gas oil by 21% over 2 years. The shift in this sector has been towards the emerging markets of propane and butane use.

A similar story applies in the **agricultural** sector, where use of propane has grown significantly in recent years whilst the use of gas oil and fuel oil have slowly declined. Gas oil remains as the main fuel source for agricultural heating and power systems, but consumption between 1999 and 2001 fell by 24%.

3.3.4 Natural Gas Consumption

The use of natural gas for both direct heating and central heating boilers has grown over the years, as appliances for this clean-burning fuel have gradually replaced solid fuel units.

The key sector for natural gas use is domestic heating. The distribution of total gas consumption across smaller combustion sources in 2001 was as follows:-

Domestic heating and cooking:	77 %
Small commercial & industrial boilers:	17 %
Agricultural power, drying & heating:	0.3 %
(Miscellaneous central heating):	7 %

In the domestic sector, gas use has been growing by 2-3 % each year from 1997 to 2001, whilst each of the other sectors have remained fairly level, with fluctuations up and down of a few percent year-to-year.

The domestic heating sector is by far the most significant gas consumer of the small-scale combustion market, totalling an estimated 379, 000 GWh of energy use in the UK in 2001.

3.3.5 Renewable Energy Consumption

The following DUKES figures for annual consumption of renewable resources in the UK in 2001, expressed in thousand tonnes of oil equivalent, are applicable to the small-scale combustion sector:-

Industrial wood waste combustion:	71, 000 tonnes oil equiv.
Domestic wood combustion:	204, 000 tonnes oil equiv.
Agricultural waste combustion:	72, 000 tonnes oil equiv.
Public sewage gas combustion:	49, 000 tonnes oil equiv.

3.4 SMALL-SCALE COMBUSTION SUB-SECTORS

3.4.1 Residential Sources

Domestic coal-burning in open fires was a significant source of particulate and other pollutants across the UK in the 1950s and 1960s, but with the development of legislation, the introduction of smoke control areas, and introduction of natural gas, domestic heating has changed significantly. The development of smokeless solid fuels and the widespread switch to gas and electricity for home heating has greatly reduced coal consumption in the domestic sector.

For example, a recent study on PM_{10} emission sources [5] estimates that since 1970, national PM_{10} emissions from the domestic sector have reduced by over 86% due primarily to the reduction in coal burning.

Emissions from domestic combustion may still be significant in small towns and villages where solid fuels are still widely used, and especially in Northern Ireland where natural gas is not widely available.

The lack of combustion controls and abatement technology on many domestic solid fuel combustion sources means that fuel often burns at relatively low temperatures, with insufficient turbulence and therefore poor mixing of volatiles

with oxygen. In particular, poor combustion of volatiles within conventional fireplaces leads to the emission of many products of incomplete combustion (PICs).

However, the combustion efficiency of smaller stoves and fireplaces can be greatly improved through the introduction of newer techniques such as catalytic combustors, staged air combustion, better insulation of the combustion chamber or preheating inlet air. Such mechanisms can reduce the release of unburned components significantly [6].

As the most significant sub-sector of the small-scale combustion market as a whole, residential sources demonstrate a significant range of technologies that have a corresponding range of relative efficiency of fuel use and pollutant emissions. Hence futher detail of this sector has been sought to enable closer inspection of the validity of emission factors for each fuel type.
From the overall consumption figures for the domestic heating sector, the order of the most commonly used fuels (that therefore require closest attention) is:-

gas > burning oil (kerosene) > steam coal > anthracite > other solid fuels

The UK domestic central heating sector is dominated by natural gas, which is estimated to be used in 76% of households [7], with oil-based systems growing their market share in recent years. The estimated numbers of new central heating installations (excluding electric) in recent years are outlined below:-

Year	Number of new central heating installations		
	Gas	Solid Fuel	Oil
1998	765, 000	31, 000	79, 000
1999	785, 000	30, 000	84, 000
2000	830, 000	30, 000	87, 000
2001	867, 000	29, 000	89, 000
2004 forecast	975, 000	27, 000	95, 000

[Source: AMA Research 2001]

Central heating systems include a range of technologies, but are dominated by combination boilers (> 50% of the market). There is a trend towards the installation of more fuel-efficient condensing boiler systems.

Solid fuel central heating systems have been in decline and now account for around 2% of domestic central heating systems. As regards domestic space heating, the use of secondary heat sources (fireplaces and stoves) for occasional use are the main use for fuels such as wood.

3.4.2 Small Commercial & Institutional Boilers

According to DUKES (from which the majority of the activity data in the NAEI is obtained) and the NAEI, the public service sector includes the following sub-sectors:-

- Public administration
- Education

- Health and veterinary services

The miscellaneous sector includes:-

- Sewage and other sanitary services
- Recreational, cultural and sporting activities
- Other service activities

This bracket of combustion sources is considered between the smaller domestic and larger CHP sources, although there is significant overlap between the technologies used in both the smaller and larger installations. There have been a series of UK-specific research projects to investigate small industrial and institutional boilers over recent years, including trials at boilers serving schools, industry and leisure facilities. Boiler sizes of 50-200 kW are typical for this sector, and hence research into furnaces and boilers around this range have been used to develop emission factors for the sector as a whole.

Note that figures for industrial space heating using LPG and burning oil have also been included within the small commercial & public sector data.

3.4.3 Agricultural Sources

The combustion of fuels in the agriculture sector is primarily for the provision of heat and power to greenhouses and other manufacturing buildings.

The key fuels pertinent to this sector are gas oil, propane (LPG) and natural gas.

This sector is one of the likely sources of significant expansion of micro-CHP units, with the on-site cogeneration of heat, power and carbon dioxide (for plant growth) being ideally suited to the demands of this sector.

Very little specific research into combustion appliances commonly used at agricultural sites has been identified within this study. However, the design and performance of these units is estimated to be similar to that applicable across other sectors (primarily the commercial and public sector). Hence the emission factors recommended for agricultural sources are frequently taken from research related to these other sub-sectors.

3.4.4 CHP plants

The growth of CHP across the UK during the 1990s has constituted a significant change in the national provision of energy and power. The environmental benefits of CHP have been identified by UK Government, and the expansion of this sector (predicted to double in volume over the next 5-7 years) plays a major role in the Government's programme to achieve carbon dioxide emission reductions, in line with the Kyoto Protocol.

The key fuels within this sector and their respective CHP market share (Source: *Digest of UK Energy Statistics, 2001*) are indicated below:-

- **Natural gas** (61 %; predominantly using combined cycle cogeneration technology)

- **Fuel Oil** (7 %; also dominated by CC cogeneration technology)
- **Coal** (6 %; predominantly Condensing Steam Turbine technology)
- **Other fuels** (24 %; "other fuels" includes coke furnace, blast furnace and gas oils)

Combined Heat and Power systems provide increased fuel efficiency compared to traditional electricity generation systems, and the environmental benefits that stem from this are a significant contributor to the UK's drive to reduce CO_2 emissions in line with the Kyoto Protocol. The UK has a target of 10 GWe (electrical output) CHP production by 2010, and the Government has implemented several incentive schemes and exempted CHP plants from the Climate Change Levy in order to promote development of CHP units [8,3].

The total capacity of CHP has grown steadily by about 7% per year throughout the 1990s, with installed capacity in 2001 of around 4.8 GWe which represents about 8% of the total electricity generation in the UK. Larger CHP plants serving industrial sites make up the majority of the total CHP capacity in the UK through 70-80 large sites of greater than 10 MWe capacity.

Hundreds of smaller schemes also exist, however, and the table below outlines the range of CHP scheme capacities during 2001:-

Electrical Capacity Range	Number of Schemes	% of number of Schemes	Total Electrical Capacity (MWe)	% of total Electrical Capacity
< 100 kW	679	43	41	1
100 – 999 kW	631	40	154	3
1 – 9.9 MW	190	12	780	16
> 10 MW	73	5	3826	80
Total	1573	100	4801	100

[DUKES 2002]

The industrial capacity of CHP serves sectors such as chemical manufacture, oil refining, paper & pulp, food & drink and iron & steel. Smaller CHP schemes have flourished within institutions and buildings such as leisure centres, hotels, hospitals, universities and community heating schemes in some cities.

The principal fuel used by CHP installations is natural gas (61% of total installed capacity in 2001 according to DUKES 2002). Fuel oil and coal are also commonly used in CHP, together with various "waste" fuels such as refinery & blast furnace gases, landfill and biogases, and solid municipal waste. The current distribution of fuel use, given as a % of total energy production in 2001 is as follows:-

Natural Gas:	61 %	
Fuel Oil:	7 %	
Coal:	6 %	
Refinery Gases:	6 %	
Renewables:	2 %	
Other fuels:	18 %	(blast furnace gas, coke oven gas & gas oil)

There are four principal types of CHP installation: steam turbine, gas turbine, combined cycle and reciprocating engines.

Steam Turbine (ST): Steam at high pressure is generated in a boiler. This category includes: **back-pressure ST** systems where steam is wholly or partly used in a turbine before being exhausted at the required pressure for the site, and **pass-out condensing ST** systems where a proportion of the steam used by the turbine is extracted from the turbine at intermediate pressure with the remainder being fully condensed before being exhausted. ST boilers used in CHP schemes can burn a wide variety of fuels (including coal, gas and oil) and provide electrical efficiencies of 10-20%, with a further 30-70% available as useful heat. ST in CHP applications typically range from a few MW_e to over 100 MW_e.

Gas Turbine (GT): These systems are often aero-engine derivatives using gas or gas-oil combustion to drive the gas turbine, using exhaust gases either directly (in some process applications) or in a waste heat boiler to produce useable steam. Conventional GT systems range from about 1 MWe upwards (although smaller microturbines are now available), and typically achieve electrical efficiency of 23-30%, with a further 50% of fuel input available as useful heat. This technology has been common in CHP since the 1980s, and the waste heat boiler can be supported by supplementary firing using a range of auxiliary fuels.

Combined Cycle (CC): These systems usually comprise gas turbines where exhaust gases are used in a steam generator, the steam from which is passed (wholly or in part) to a steam turbine system. CC is suited to larger installations of about 7 MWe and above, and typically achieve higher electrical efficiency (up to 50%) than simple cycle schemes.

Reciprocating Engine (RE): These systems are commonly based on auto or marine engines converted to run on gas, using compression or spark ignition, and are mainly used where production of hot water, rather than steam, is the main requirement. These systems range from 100 kW_e to around 5 MW_e, and operate at around 28-33% electrical efficiency, with 33-50% of the fuel input available as useful heat.

In recent years, the trend has been towards the use of gas turbine and combined cycle technology, and away from steam turbine technology, resulting in an increased ratio of electrical to heat output.

CHP Trends

The UK Government aims to increase CHP capacity to 10 GWe by 2010, and a recent Royal Commission on Environmental Pollution report proposes an increase in the use of CHP and community heating to meet carbon dioxide emission reduction targets of 60% by 2050. The Commission suggests that the UK's future energy infrastructure should contain the following:-

- approx. 20 medium scale (< 60 MW_e) CHP plants fuelled by Municipal Solid Waste
- approx. 4,000 small scale (<10 MW_e) CHP plants fuelled by biomass such as agricultural & forestry wastes and energy crops
- approx. 2.4 million gas-fired domestic CHP units

It is anticipated that the continued emergence of new technologies such as micro-turbines, fuel cells and domestic-scale CHP will continue to progress CHP technology into new markets.

Small-scale CHP (< 1 MWe) already plays a significant role in sectors such as hotels, leisure centres, hospitals and universities, with several hundred such installations UK-wide. These units are largely based on gas-driven reciprocating engine technology with engine jacket & exhaust heat recovery. The development of such units for small-scale community heating schemes is a potential area for significant CHP growth.

New low-emission **microturbines** are becoming commercially viable, especially within the horticultural sector; units of typically 30-500 kWe that provide heat, power and CO_2 to large glasshouses with significantly cleaner emissions (especially regarding NO_x levels) have started to replace traditional diesel engines. These units are also popular as a standby power-source for building services and some designs are fuel-flexible.

The development of **fuel cell technology** provides great potential for small-scale cogeneration applications. Electricity is generated directly from chemical fuel conversion at up to 60% efficiency, and heat is recovered from the chemical process, producing up to 90% total energy efficiency. The technology to obtain such a significant power efficiency lends itself to modern office facilities where IT and air-conditioning requirements are high electricity consumers. Fuel cells currently remain at the early stages of commercial viability & development, but the advantages of such technology suggest that it will play a significant future role.

3.5 SUMMARY OF COMMON CONTROL MEASURES

3.5.1 Domestic Sector

Frequently no combustion controls or flue gas treatment is evident for open fires or closed stove combustion where these units are primarily used for secondary space heating. Research into the improvement of combustion within such appliances suggests that the implementation of **Staged Air Combustion** may provide a cost-efficient approach to emissions reduction for smaller fireplaces and stoves, particularly for the reduction of NO_X gases [6]. Any secondary measures for cleaning flue gases are usually restricted to larger combustions sources on economic grounds.

Central heating boilers and stoves used to provide the primary space heating and hot water provision in UK households will vary in their combustion efficiency according to their design, control and state of repair. However, these systems do provide some degree of combustion control, with significant progress in combustion efficiencies and emission reductions evident in modern appliances available on the UK market.

3.5.2 Public/Commercial and Agricultural Sectors

The most commonly used fuels in these sectors are natural gas and gas oil. These fuels typically burn much cleaner than the solid fuel options that are evident across the residential sector, and there is typically greater investment (and closer attention to cost-control and operating efficiency) for regular servicing and maintenance of larger boilers in these sectors.

In addition, the larger the boiler, the more cost-effective the application of emission abatement technology such as NO_X-controls and particulate abatement kit, and these technologies are evident on several designs of small-scale commercial boilers.

3.5.3 Combined Heat and Power

Similar to the public, commercial and agricultural sectors, CHP is fuelled largely by cleaner-burning fuels (mainly natural gas) and the investment in combustion controls and pollution abatement technology becomes a more significant factor as boiler capacity increases.

The advent of more fuel-efficient cogeneration units, and the increase in uptake of micro-CHP across a range of industrial and public service sectors indicates that the development of this sector of the UK heat & power market plays a significant role in target pollutant emission reduction.

4 Coal

4.1 USE

Coal may be burnt domestically in either closed appliances or in open fires as a heating source. The main pollutants of concern from the combustion of bituminous and sub-bituminous coal include PM_{10}, CO and nitrogen oxides (NO_X).

At present, the following factors are used in the NAEI for the combustion of coal in the small-scale combustion sector (NO_x is expressed as NO_2) :-

Sector	NO_X	VOC	CO	PM_{10}	PCDD/Fs
	g/kg	g/kg	g/kg	g/kg	g/Mt
Domestic	1.42[a]	14	45[b]	10.4[c]	3.04[d]
Public Service	3.96	0.05	4.1	2.5	50.54
Agriculture	4.31	0.05	4.1	2.5	2.4
Miscellaneous	3.96	0.05	4.1	2.5	2.4
Other Industry	4.65	0.05	4.1	2.5	2.4

[a = CORINAIR 1992, b = USEPA (1977), c = S. Eggleston 1997, d = CPL EF Draft Report.]

4.2 OXIDES OF NITROGEN

The following table summarises NO_X emission factors (and sources) for small-scale coal combustion, identified during this study :-

Sub-sector	REF.	NO_X EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to domestic open fires)
Domestic closed stove	15	2.3	g/kg	UN ECE, 2002: dutch data, domestic coal use
	23	8	g/kg	CRE, 1999: Uk data, 12.5kW stove, anthracite, medium burn rate
Domestic Boiler	12	6.2	g/kg	ERA, 2000: UK research, bituminous coal in boilers
Commercial Boiler	-	-	-	(no data identified specific to commercial boilers)
Agricultural heater	15	9.3	g/kg	UN ECE, 2002: dutch data, agricultural coal use
CHP	18	9.8	g/kg	Australian data: avge. from AUS power stations fired on black coal
	17	8	g/kg	WSL, 1993: UK data, coal-fired 500MWe power station, low-NO_X

NO_X emissions from coal combustion are primarily in the form of nitric oxide (NO), although some is emitted in the form of nitrogen dioxide (NO_2).

4.3 CARBON MONOXIDE

The following table summarises carbon monoxide emission factors (and sources) for small-scale coal combustion, identified during this study:-

Sub-sector	REF.	CO EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to domestic open fires)
Domestic closed stove	15	46.4	g/kg	UN ECE, 2002: dutch data, domestic coal use
	23	709	g/kg	CRE, 1999: Uk data, 12.5kW stove, anthracite, medium burn rate
Domestic Boiler	12	1.8	g/kg	ERA, 2000: UK research, bituminous coal in boilers
Commercial Boiler	10	10	g/kg	AEAT, 2001: bituminous coal, 500kW boiler
Agricultural heater	15	3.1	g/kg	UN ECE, 2002: dutch data, agricultural coal use
CHP	18	0.3	g/kg	Australian data: avge. from AUS power stations fired on black coal
	17	0.25	g/kg	WSL, 1993: UK data, coal-fired 500MW power station, low-NO_X

The above data illustrates the variability of CO emissions from domestic coal use, but the figures for larger plant are much more consistent.

4.4 PM_{10} EMISSION FACTORS

The following table summarises the PM_{10} emission factors (and sources) for small-scale coal combustion, identified during this study:-

Sub-sector	REF.	PM_{10} EF	Units	Comment
Domestic open-fire	13	9 to 11	g/kg	CRE, 1997: household & texan star (bituminous) coal, < 10kW open fire
	14	40.4	g/kg	CPL, 2002: yorkshire (bituminous) housecoal, < 5kW open fire
Domestic closed stove	15	4	g/kg	UN ECE, 2002: dutch data, "domestic coal use"
	2	3.4	g/kg	IIASA, 2001: german data, "uncontrolled domestic coal furnace"
Domestic boiler	12	6	g/kg	ERA, 2000: UK research, bituminous coal
	2	2.8	g/kg	IIASA, 2001: german data, "uncontrolled domestic coal boiler"
Commercial boiler	2	1.4	g/kg	IIASA, 2001: german data, "uncontrolled industrial coal boiler"
Agricultural heater	15	0.1	g/kg	UN ECE, 2002: dutch data, "agricultural coal use"
CHP	-	-	-	(None identified for PM_{10})

CPL Study, 2002

The CPL study measured emissions and subsequently calculated emission factors from a range of pollutants released to air during the combustion of coal on an

open fire. The tests were carried out using bituminous coal and produced an estimated emission factor of 40.4 g PM_{10} per kg of coal burnt.

CRE Study, 1997

The first is a report from the Coal Research Establishment (CRE) was prepared for Belfast City Council to support them as part of the first phase implementation of the air quality provisions of the Environment Act 1995. From the tests carried out by CRE an emission factor range for PM_{10} from coal burnt in open appliances was determined to be 9 to 11 g PM_{10} per kg of coal burnt.

This corresponds favourably to the PM_{10} emission factors currently used in the NAEI, suggesting that coal burning on an open fire is represented well by the NAEI calculations.

Summary

PM_{10} emission factors obtained from closed appliances tend to be substantially lower than those obtained from open fires. Whilst the PM_{10} emission factors reported in the CRE study are similar to that currently used in the NAEI, the emission factor cited in the CPL study is significantly higher than anything else reported. Note that uncontrolled PM_{10} emissions from coal-fired boilers include the ash from the combustion of the fuel as well as semi-volatile material resulting from incomplete combustion.

4.5 DIOXINS AND FURANS, PCBS

The following table summarises the dioxin and furan and PCB (polychlorinated biphenyl) emission factors (and sources) for small-scale coal combustion, identified during this study:-

Sub-sector	REF.	Substance: EF	Units	Comment
Domestic open-fire	14	PCDD/Fs: 2.9	gTEQ/MT	CPL, 2002: yorkshire (bituminous) housecoal, < 5kW open fire
	14	PCBs: 6.1	gTEF/MT	
Domestic closed stove	-	-	-	(no data identified specific to domestic stoves)
Domestic Boiler	21	PCCD/Fs: 1-2.5	gTEQ/MT	EMEP/CORINAIR default factors for “small-scale coal combustion”
Commercial Boiler	10	PCDD/Fs: 51	gTEQ/MT	AEAT, 2001: bituminous coal, 500kW boiler
Agricultural heater	-	-	-	(no data identified specific to agricultural sources)
CHP	17	PCDD/Fs: 0.51-0.85	gTEQ/MT	WSL, 1993: UK data, coal-fired 500MW_e power station, low-NO_X

4.6 VOC EMISSION FACTORS

4.6.1 VOC Emission Factors: 1998 UK Study

A 1998 study for the European Commision [9] summarised UK research into the emissions of VOCs from coal-burning in appliances ranging from domestic open fires and closed stoves to 500 MW_e pulverised fuel boilers. Specific findings for different sorts of UK appliances are outlined below, but in summarising total UK VOC emissions, the report stated the following:-

"This study has confirmed that the domestic sector is the major source of VOC emissions from coal combustion, accounting for about 95% of the total emissions, and this predominantly arises from the combustion of bituminous coal on open fires."

The figures shown below clearly demonstrate that the domestic sector is potentially a large source of VOC arisings from coal combustion, and hence the general trend away from domestic coal consumption and towards cleaner fuels such as oil and gas is likely to be beneficial in terms of VOC emission reductions.

Plant Type & Rating	Fuel	EF, Methane (g/kg)	EF, NMVOCs (g/kg)	No. of tests
Domestic open grate	bituminous	15.7	14.0	2
Domestic open grate	smokeless	5.8	4.9	2
17 kW underfeed	bituminous	0.43	0.61	8
13 kW gravity feed	anthracite	2.0	1.7	4
0.9 to 48 MW	bituminous	0.01	0.05	42
500 MWe	bituminous	0.01	0.03	5

[Source: "Emission of VOCs from Coal-Fired Appliances", EUR 17444 EN, 1998]

Further detail regarding the different appliances tested are summarised below.

Domestic Open Fires

VOC emissions vary markedly over a combustion cycle, with the highest VOC emissions evident at start-up and during re-fuelling (both periods where combustion efficiency is at its lowest). The low fuel-bed temperature results in the release of unburnt volatiles and smoke from the coal, and then VOC emissions reduce progressively during the combustion cycle until at the "red-fire" stage, emission factors are an order of magnitude lower than during refuel or start-up.

The following emission factors were derived:-

Start-up / Refuel	30 g/kg
Red-fire stage	2.3 g/kg
Mean EF for complete cycle	14 g/kg

Speciation of the VOC emissions indicated that methane was the highest emission, with low-RMM alkanes and alkenes (C_2-C_4) and benzene / toluene species predominating.

During the same research programme, smokeless fuels were burned in an open grate, and resultant VOC emission factors were found to be lower than for

bituminous coal but with very similar emission profile of VOC species. The mean EF for a complete combustion cycle of smokeless fuels was derived as 4.9 g/kg, but this figure was derived from tests from a single fuel brand, and hence may not be representative of smokeless fuels in general.

Enclosed Domestic Stoves & Boilers

The study also included monitoring of two enclosed appliances, each with heat exchangers for hot water supply: an underfeed stoker boiler fired on bituminous coal and a gravity-fed boiler fired on anthracite. Significant variation in VOC emission measurements was observed across 8 nominally similar tests conducted on the underfeed stoker, clearly demonstrating the inherent variability of coal combustion in small appliances and illustrating the degree of uncertainty in the results. The derived emission factors are shown below, with the range of results from individual tests in brackets:-

Underfeed stoker (8 tests)	0.6 g/kg	(range: 0.1 - 1.7 g/kg)
Gravity boiler (4 tests)	1.7 g/kg	(range: 0.4 – 3.3 g/kg)

Note that the emission factors are significantly lower for enclosed appliances compared to open fires. This is due primarily to the higher combustion efficiency of the enclosed appliances from continuous feeding of fuel into a hot fuel bed rather than the inefficient cycling of batch-fed open fires.

From previous studies, anthracite is normally expected to generate lower volatiles under the same firing conditions, compared to bituminous coals. In this study, the bituminous coal-fed underfeed stoker has generated emission factors lower than the anthracite-fed gravity boiler. These data suggest that the VOC emission can be controlled more by appliance design than fuel type.

Industrial and Power Station Plant

The 1998 study included a comprehensive study of VOC emissions from a wide range of industrial coal-fired power units of the following capacities: 0.9 MW, 1 MW, 5 MW, 19 MW, 43 MW, 48 MW and 500 MWe (about 1400 MWth). The findings from this research are therefore applicable across a range of coal-fed commercial & institutional boilers as well as the full range of coal-fired CHP units in the UK.

The VOC emissions from all of these units were found to be very low (less than 0.1 g/kg) and around 2 orders of magnitude below the emission factors derived for domestic open fires. The emission factor for the coal consumption in the industrial and commercial sector may be derived from the mean figure from the 0.9 – 48 MW plants in this study, 0.05 g/kg.

The factor derived for the 500 MW unit was 0.03 g/kg, indicating a high degree of combustion control on larger facilities.

In order to determine whether the emission factor used for the UK NAEI should tend towards the open or closed fire results, the proportion of coal burnt in domestic open fires compared to that burnt in closed stoves must be estimated.

The assumption quoted in the report in 1998 was that 90% of domestic-sector bituminous coal consumption was burned on open fires. The derivation of a single emission factor for domestic coal combustion based on this assumption is shown below:-

$$(0.9 \times 14) + (0.1 \times 0.6) = 12.7 \text{ g/kg}$$

Coal consumption in the agricultural sector is likely to be in the form of units more akin to the commercial / institutional sector, and therefore the emission factors applicable to these sectors are considered most appropriate for agricultural coal consumption.

4.6.2 VOC Emission Factors: Other Sources

In addition to the above UK-focussed study, the following sources also provide research into VOC emission factor development. The table below summarises the findings for "VOC" emission factors and also "NMVOC" (Non-Methane Volatile Organic Compounds) emission factors.

Sub-sector	REF.	VOC EF	Units	Comment
Domestic closed stove	15	1.9	g/kg	UN ECE, 2002: dutch data, **total VOCs** "domestic coal use"
Domestic boiler	12	0.02	g/kg	ERA, 2000: UK research, **total VOCs** bituminous coal in boilers
	16	1.2-6.0	g/kg	Rentz et al, 1998: hard coal, **NMVOC**, 35kW boiler, improved-uncontrolled
	16	2.6-12.9	g/kg	Rentz et al, 1998: brown coal, **NMVOC**, 35kW boiler, improved-uncontrolled
Commercial boiler	16	0.2-0.9	g/kg	Rentz et al, 1998: hard coal, **NMVOC**, 200 kW boiler, improved-uncontrolled
	16	0.2-1.0	g/kg	Rentz et al, 1998: brown coal, **NMVOC**, 200 kW boiler benchmark / improved
Agricultural heater	15	1.1	g/kg	UN ECE, 2002: dutch data, **total VOCs** "domestic coal use"
CHP	17	0.06	g/kg	WSL: UK data, **total VOCs**, 500 MW_e power station, coal-fired, low-NO_X
	18	0.05	g/kg	Australian data: avge. **NMVOC** from AUS power stations fired on black coal
	16	0.09	g/kg	Rentz et al, 1998: hard coal, **NMVOC**, 200 kW boiler improved & abated
	16	0.10	g/kg	Rentz et al, 1998: brown coal, **NMVOC**, 200 kW boiler improved & abated

With the exception of the very low figure obtained from the ERA research in 2000, these figures demonstrate a consistent reduction in VOC releases as the scale of combustion unit increases, from 1.2-12.9 g/kg for domestic sources through to < 0.1 g/kg for power stations and larger boilers.

These results are consistent with the findings of the 1998 UK study.

4.7 PAHS & BENZENE EMISSION FACTORS

PAHs (polycyclic aromatic hydrocarbons) refer to a large group of chemical compounds with a similar structure comprising two or more joined aromatic carbon rings. The main environmental impact of PAHs relate to their health effects, focusing on their carcinogenic properties. The NAEI reports on the sixteen of most concern as indicated by the USEPA.

The following table summarises the PAH, PCN (Polychlorinates naphthalenes), benzene and benzo(a)pyrene emission factors (and sources) for small-scale coal combustion, identified during this study:-

Sub-sector	REF.	Substance: EF	Units	Comment
Domestic open-fire	14	PCNs: 0.68	g/kT	CPL, 2002: yorkshire (bituminous) housecoal, < 5kW open fire
	14	33 PAHs: 254	T/MT	
Domestic closed stove	19	B(a)P: 0.1	g/T	POPs Inventory, 2003: Russian data for residential coal use
Domestic boiler	10	B(a)P: 1.5	g/kT	POPS Inventory: Polish data, domestic use of hard coal
	10	B(a)P: 0.9	g/kT	POPS Inventory: Polish data, domestic use of brown coal
	21	B(a)P: 0.6-2.0	g/T	EMEP/CORINAIR default factors for "small-scale coal combustion"
Commercial boiler	22	B(a)P: 13-56	g/kT	MSC-E, 2001: Russian data, low-capacity heat-power boilers
	22	B(a)P: 9.2	g/kT	MSC-E, 2001: Russian data, heat-power boilers
	10	B(a)P: 2.3	g/kT	AEAT, 2001: bituminous coal, 500kW boiler
	10	Benzene: < 0.01	Kt/MT	
	10	33 PAHs: 1650	g/kT	
	19	B(a)P: 14	g/kT	POPs Inventory, 2003: Russian data for industry / public utility use of coal
Agricultural heater	10	B(a)P: 1.5	g/kT	POPS Inventory: Polish data, agricultural use of hard coal
	10	B(a)P: 0.9	g/kT	POPS Inventory: Polish data, agricultural use of brown coal
CHP	19	B(a)P: 9.2	g/kT	POPs Inventory, 2003: Russian data for power plant use of coal

Of specific relevance to the UK emission inventory, the 2001 study by Collings, AEA Technology [10] provides a detailed breakdown of specific PAHs from a small coal-fired boiler. The findings of this report are summarised below.

Collings et al [10] provides emission factors for PAHs, CO, benzene and dioxins from tests that were carried out on a small coal-fired school boiler. Comparison against existing NAEI Emission Factors is shown below.

Pollutants	NAEI 2000 Emission Factors (kg/Mt)	Collings et al, 2001 Emission Factors (kg/Mt)
Acenaphthene	2622	9.5
Acenaphthylene	3578	39.8
Anthracene	925	0.9
Benzo[a]anthracene	894	7.7
Benzo[a]pyrene	775	2.3
Benzo[b]fluoranthene	35	35.4
Benzo[ghi]perylene	408	8.9
Benzo[k]fluoranthene	12	24
Chrysene	835	31.1
Dibenzo[ah]anthracene	896	3.7
Fluoranthene	1502	100.5
Fluorene	8105	1.7
Indeno[1,2,3 – cd]pyrene	596	17.5
Napthalene	61703	1055
Phenanthrene	3283	267
Pyrene	1491	9.3
	(kt/Mt)	**(kt/Mt)**
Benzene	0.0019	< 0.01
	(g/Mt)	**(g/Mt)**
Dioxins	2.4	51

The average benzene emission factor determined in this study are higher than those currently used in the NAEI. However, the benzene measurements are subject to a high degree of uncertainty as the measured concentrations were below the limit of detection.

The PAH emission factors are lower than those used in the current NAEI, sometimes by several orders of magnitude. On the other hand, the dioxin emission factor obtained in the Collings study is significantly higher than that currently used in the NAEI.

4.8 OXIDES OF SULPHUR

The following table summarises oxide of sulphur emission factors (and sources) for small-scale coal combustion, identified during this study:-

Sub-sector	REF.	SO_2 EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to domestic open fires)
Domestic closed stove	15	13	g/kg	UN ECE, 2002: dutch data, domestic coal use
	23	104	g/kg	CRE, 1999: Uk data, 12.5kW stove, anthracite, medium burn rate
Domestic Boiler	12	17.2	g/kg	ERA, 2000: UK research, bituminous coal in boilers
Commercial Boiler	-	-	-	(no data identified specific to commercial boilers)
Agricultural heater	15	14.2	g/kg	UN ECE, 2002: dutch data, agricultural coal use
CHP	17	50	g/kg	WSL, 1993: UK data, coal-fired 500MW power station, low-NO_X

5 Coke & Manufactured Solid Fuels

5.1 USE AND FUEL TYPES

A wide range of solid smokeless fuels are used in the UK residential heating market. There are three main classes; natural smokeless fuels, manufactured smokeless fuels and washed high volatile bituminous coals.

Anthracite and dry steam coal are examples of natural smokeless fuels. Manufactured smokeless fuels (MSF) include cokes and briquetted fuels. Coke is the solid residue obtained from coal or lignite by heating it to a high temperature in the absence or near absence of air. It is high in carbon, low in moisture and organic matter. The major manufactured smokeless fuels in the UK include Phurnacite, Homefire, Sunbrite and Coalite. Like coal, these solid fuels can be burnt in the domestic sector either on open fires or in closed appliances.

5.2 EMISSION FACTORS FOR COKE

The NAEI uses the following emission factors for the combustion of coke in the small-scale combustion sector:

Sector	NO_X	VOC	CO	PM_{10}	PCDD/Fs
	g/kg	g/kg	g/kg	g/kg	g/Mt
Domestic	1.33[a]	4.9	45	0.2875[b]	2.4[c]
Public Service	4	0.05	4.1	0.2875	2.4
Agriculture	4	0.05	4.1	0.2875	2.4
Miscellaneous	4	0.05	4.1	0.2875	-
Other Industry	4.8	0.05	4.1	0.2875	2.4

[a = Corinair 1992, b = S.Eggleston, 1997, c = EF from “other industry & power stations”]

The following table summarises VOC, CO, SO_2, NO_X and PM_{10} emission factors (and sources) for small-scale coke combustion, identified during this study:-

Sub-sector	REF.	Species	EF	Units	Comment
Domestic open-fire	13	PM_{10}	2.3-2.8	g/kg	CRE, 1997: pet coke blend, open fire
	9	VOC	0.2-0.6	g/kg	BCC, 1998: domestic coke use
Domestic closed stove	13	PM_{10}	2.6-3.2	g/kg	CRE, 1997: pet coke blend, closed stove
	23	CO	1125	g/kg	CRE, 1999: 12.5kW stove, coke, medium burn rate
		SO_2	127	g/kg	
		NO_X	7	g/kg	
Domestic Boiler	15	VOC	2.7	g/kg	UNECE, 2002: dutch data, Domestic coke use
		SO_2	11.1	g/kg	
		NO_X	11.4	g/kg	
		CO	370	g/kg	
		PM_{10}	0.2	g/kg	
	16	NM VOC	1.3-6.6	g/kg	Rentz et al, 1998: coke, 35kW boiler benchmark / improved
Commercial Boiler	9	VOC	0.1-0.9	g/kg	BCC, 1998: industrial coke use
	16	NM VOC	0.2-0.9		Rentz et al, 1998: coke, 200kW boiler benchmark / improved
Agricultural	-	-	-	-	(no data identified specific to these sectors)
CHP	-	-	-	-	

5.3 MANUFACTURED SOLID FUELS (MSF) EMISSIONS

At present the following emission factors are used in the NAEI for the burning of manufactured solid fuels in the small-scale combustion sector:-

Sector	NO_X	VOC	CO	PM_{10}	PCDD/Fs
	g/kg	g/kg	g/kg	g/kg	g/Mt
Domestic	1.32[a]	4.9	45[b]	5.6[c]	3.0
Miscellaneous	3.96	0.05	4.1	0.23	-
Other Industry	4.75	0.05	4.1	0.23	2.4

[a = CORINAIR 1992, b = USEPA 1977, c = S Eggleston, 1997.]

The following table summarises VOC, CO, SO_2, NO_X and PM_{10} emission factors (and sources) for small-scale MSF combustion, identified during this study:-

Sub-sector	REF.	Species	EF	Units	Comment
Domestic open-fire	13	PM_{10}	0.9-1.6	g/kg	CRE, 1997: smokeless coal brands, open fire < 10kW
Domestic closed stove	13	PM_{10}	1.0-1.2	g/kg	CRE, 1997: smokeless coal brands, closed stove < 10kW
	24	CO	275	g/kg	USEPA, 2000: developing world stove trials, charcoal
		NM VOC	10.5	g/kg	
	24	CO	121	g/kg	USEPA, 2000: developing world stove trials, char briquette
		NM VOC	16.1	g/kg	
	23	CO	1190	g/kg	CRE, 1999: 12.5kW stove, manufactured briquettes, medium burn rate
		SO_2	75	g/kg	
		NO_X	4	g/kg	
Domestic Boiler	15	VOC	0.3-7.7	g/kg	UNECE, 2002: swedish data, pellet boilers, 3-6 kW
		NO_X	2.0-2.2	g/kg	
	15	VOC	0-15	g/kg	UNECE, 2002: swedish data, pellet boilers, 1.8-2 MW
		NO_X	0.5-1.1	g/kg	
		CO	4-226	g/kg	
Commercial Boiler	15	VOC	0.1	g/kg	UNECE, 2002: swedish data, briquette boilers, 1.8-2 MW
		NO_X	1.1	g/kg	
		CO	8.3	g/kg	
Agricultural	-	-	-	-	(no data identified specific to these sectors)
CHP	-	-	-	-	

6 Wood & Biomass

6.1 USE

In the UK, wood is typically burnt domestically for heating on either open fireplaces or in various types of closed stoves. The main pollutants of concern from wood burning are particulates (PM_{10}), VOCs, PAHs and nitrogen oxides (NO_X).

During this study, several sources of data pertinent to biogas use in the small-scale combustion sector were identified. However, biogas is not used widely across the UK and detailed investigation into emission factors for biogas was not considered an efficient use of resources in this study.

The burning of wood and biomass has received more and more research effort in recent years, both from an environmental and a direct human health impact perspective, as the widespread use of biomass in developing countries has been identified as a potentially significant source of heavy metal and other toxin exposure.

The wide array of research results demonstrate that the combustion of wood and biomass fuels is subject to a much greater degree of variability than fossil fuel combustion. The emission range of a given component may vary considerably depending on factors such as:-

- Type of fuel
- Type of combustion unit
- Pre-treatment or seasoning of fuel source
- Combustion conditions

The NAEI currently uses the following emission factors for the burning of wood in the domestic sector:-

Sector	NO_X	VOC	CO	Benzene	PCDD/Fs	Benzo(a) pyrene	PM_{10}
	g/kg	g/kg	g/kg	g/kg	g/Mt	g/t	g/kg
Domestic	0.72[a]	5.4	99.3[b]	1.6	0.24	1.3	7.9[c]

[a = Corinair 1992, b = IPCC Guidelines, c = CPL Report, open fire study.]

As yet, there are no emission factors within the NAEI that are pertinent to manufactured wax-logs or other wood-derived solid fuels used in the domestic sector. The energy content of manufactured wax logs can be as much as 75% higher (per unit mass) than seasoned wood, with moisture contents as low as 3%, compared to less than 20% for well-seasoned wood.

Emission studies in the USA have indicated that manufactured wax-logs and densified firelogs produce significantly lower emissions of target pollutants, compared to well seasoned “cordwood”. Particulate emissions were found to be

69% lower on average for manufactured wax logs, with CO emissions reduced by an average of 88%. [11]

6.2 PM_{10} EMISSION FACTORS

The following table summarises the PM_{10} emission factors (and sources) for small-scale wood combustion, identified during this study:-

Sub-sector	REF.	PM_{10} EF	Units	Comment
Domestic open-fire	14	7.9	g/kg	CPL, 2002: UK study, seasoned hardwood
	2	1.5	g/kg	IIASA, 2001: german data, wood use in uncontrolled fireplaces
Domestic closed stove	2	1.5	g/kg	IIASA, 2001: german data, uncontrolled wood stoves
		1.0-2.0	g/kg	IIASA, 2001: dutch data, uncontrolled wood heating
		1.5-2.9	g/kg	2001: RAINS data for domestic wood heating
Domestic boiler	2	0.5	g/kg	IIASA, 2001: german data, uncontrolled Domestic wood boilers
Commercial boiler	25	0.44	g/kg	AEAT, 2001: 1.5 MW wood boiler with cyclone abatement
	12	3.6	g/kg	ERA, 2000: boiler Efs, wood
Agricultural	-	-	-	(no data identified specific to these sectors)
CHP	-	-	-	

Houck et al, 2001 [11] provides a TPM emission factor of 11.8 kt/mt for domestic wood combustion. The study was based on 388 tests on 112 different fireplaces, and constitutes a comprehensive study on the subject. This compares to a PM_{10} emission factors of 7.9 kt/mt currently used in the NAEI.

The NAEI emission factor is obtained from a recent CPL Report (Perry, 2002). The PM_{10} emission factor quoted in AP-42 is substantially higher than that quoted in the CPL Report.

6.3 VOC EMISSION FACTORS

The following table summarises the VOC emission factors (and sources) for small-scale wood combustion, identified during this study:-

Sub-sector	REF.	VOC EF	Units	Comment
Domestic open-fire	6	5.2	g/kg	Norway Inst of Tech, 1995: fireplaces
	9	0.9-8.0	g/kg	BCC, 1998:UK data, wood in domestic fireplaces
Domestic closed stove	6	17.5	g/kg	Norway Inst of Tech, 1995: traditional wood stoves, **UHC as CH_4**
		6.7	g/kg	Norway Inst of Tech, 1995: traditional wood stoves, **VOCs**
		2	g/kg	Norway Inst of Tech, 1995: modern wood stoves, **UHC as CH_4**
Domestic boiler	16	1.0-4.8	g/kg	Rentz et al, 1998: 35kW boiler, wood /charcoal, benchmark - improved
	6	13.3	g/kg	Norway Inst of Tech, 1995: wood boilers, **UHC as CH_4**
Commercial boiler	15	0.5	g/kg	UNECE: Swedish data, 1.8-2 MW wood chip boilers
	12	0.1	g/kg	ERA, 2000: wood boiler
	6	0.04	g/kg	Norway Inst. Of Tech, 1995: stoker burners, **UHC as CH_4**
		0.67	g/kg	Norway Inst. Of Tech, 1995: grate burners, **UHC as CH_4**
	9	0.6-1.0	g/kg	BCC, 1998: UK wood use in industrial appliances
	16	0.16-0.80	g/kg	Rentz et al, 1998: 200 kW boiler, wood /charcoal, benchmark - improved
Agricultural	15	< 0.01	g/kg	UNECE: Swedish data, 1.8-2 MW logging residue boilers
CHP	6	0.01	g/kg	Norway Inst. Of Tech, 1995: Fluidized bed, **UHC as CH_4**
		0.02	g/kg	Norway Inst of Tech, 1995: Cyclone furnaces

6.4 PAH AND BENZENE EMISSION FACTORS

The following table summarises the PAH, benzene and other air toxin emission factors (and sources) for small-scale wood combustion, identified during this study:-

Sub-sector	REF.	Substance: EF	Units	Comment
Domestic open-fire	14	PCBs: 1.2	gTEF/MT	CPL, 2002: seasoned hardwood, < 5kW open fire
		PCNs: 0.12	g/kT	
		33 PAHs: 43	g/T	
	11	16-PAH: 220	g/T	OMNI, 2001: conventional stoves
		16-PAH: 130	g/T	OMNI, 2001: high-tech non-cat stoves
		16-PAH: 160	g/T	OMNI, 2001: catalytic stoves
	6	PAH: 1.1	g/T	Norway Inst of Tech: fireplaces
Domestic closed stove	20	B(a)P: 2.5	g/kT	POPS Inventory: Polish data, domestic wood use
	21	B(a)P: 5	g/T	EMEP/CORINAIR default fig, fireplaces
	26	PAH: 280-400	g/T	USEPA, 1998: conventional – improved wood stoves
		PAH: 160	g/T	USEPA, 1998: test stove A
		PAH: 160	g/T	USEPA, 1998: test stove B
	6	PAH: 35	g/T	Norway Inst of Tech: traditional wood stoves
		PAH: 0.3	g/T	Norway Inst of Tech: modern wood stoves
	19	B(a)P: 2	g/T	POPs Inventory, 2003: Russian data for residential use of wood
Domestic boiler	9	PAH: 0.3	g/T	Norway Inst of Tech: wood boilers
	21	B(a)P: 1.5-5	g/T	EMEP/CORINAIR default factors for "small-scale wood combustion"
Commercial boiler	25	Benzene: < 20	g/T	AEAT, 2001: 1.5 MW wood-burning furnace with cyclone
		33 PAH: 41	g/kT	
		PCBs: 0.37	gTEF/MT	
	6	PAH: 0.1	g/T	Norway Inst of Tech: stoker burners
		PAH: 40	g/T	Norway Inst of Tech: grate burners
Agricultural heater	20	B(a)P: 2.5	g/kT	POPS Inventory: Polish data, Agricultural wood use
CHP	6	PAH: 0.04	g/T	Norway Inst of Tech: fluidized bed

6.5 DIOXINS AND FURANS

The following table summarises the dioxin and furan emission factors (and sources) for small-scale wood combustion, identified during this study:-

Sub-sector	REF.	PCDD/F EF	Units	Comment
Domestic open-fire	14	0.23	gTEQ/MT	CPL, 2002: UK study, seasoned hardwood
Domestic closed stove	21	5	gTEQ/MT	EMEP/CORINAIR default figure for small-scale wood furnaces
Domestic boiler	21	1.0-5	gTEQ/MT	EMEP/CORINAIR default figure for small-scale wood combustion
Commercial boiler	25	12.6	gTEQ/MT	AEAT, 2001: 1.5 MW wood boiler with cyclone abatement
Agricultural	-	-	-	(no data identified specific to these sectors)
CHP	-	-	-	

6.6 CARBON MONOXIDE

The following table summarises the CO emission factors (and sources) for small-scale wood combustion, identified during this study:-

Sub-sector	REF.	CO EF	Units	Comment
Domestic open-fire	6	67	g/kg	Norway Inst of Tech, 1995: fireplaces
	11	64	g/kg	OMNI review, 2001: domestic wood use
Domestic closed stove	6	70	g/kg	Norway Inst of Tech, 1995: traditional wood stoves
		17	g/kg	Norway Inst of Tech, 1995: modern wood stoves
Domestic boiler	6	50	g/kg	Norway Inst of Tech, 1995: wood boilers
Commercial boiler	15	39	g/kg	UNECE: Swedish data, 1.8-2 MW wood chip boilers
	12	6.2	g/kg	ERA, 2000: wood boiler
	6	4.6	g/kg	Norway Inst. Of Tech, 1995: stoker burners
		19	g/kg	Norway Inst. Of Tech, 1995: grate burners
	25	2.6	g/kg	AEAT, 2001: 1.5 MW wood furnace
Agricultural	15	0.42	g/kg	UNECE: Swedish data, 1.8-2 MW logging residue boilers
CHP	6	0	g/kg	Norway Inst. Of Tech, 1995: Fluidized bed
		0.38	g/kg	Norway Inst of Tech, 1995: Cyclone furnaces

Houck et al [11] quotes a carbon monoxide emission factor of 64.1 kt/mt wood burnt for domestic fireplaces. This is around two thirds of the figure currently used in the UK NAEI. The Houck et al study has reviewed 24 studies and is therefore based on a substantial dataset compared to the IPCC guidelines (used in the NAEI). It is therefore suggested that consideration is given to amending

the NAEI emission factor for carbon monoxide emissions from domestic wood combustion.

6.7 OXIDES OF NITROGEN

NO_X emissions from domestic wood-burning are determined primarily by combustion control and nitrogen content of the wood. For example, some wood sources such as plywood have a relatively high nitrogen content, leading to higher NO_X emission levels. [6]

The following table summarises the NO_X emission factors (and sources) for small-scale wood combustion, identified during this study:-

Sub-sector	REF.	NO_X EF	Units	Comment
Domestic open-fire	-	-	-	(No data identified specific to this sector)
Domestic closed stove	6	0.29	g/kg	Norway Inst of Tech, 1995: traditional wood stoves
		0.58	g/kg	Norway Inst of Tech, 1995: modern wood stoves
Domestic boiler	6	1.0	g/kg	Norway Inst of Tech, 1995: wood boilers
Commercial boiler	15	0.25	g/kg	UNECE: Swedish data, 1.8-2 MW wood chip boilers
	12	0.7	g/kg	ERA, 2000: wood boiler
	6	1.0	g/kg	Norway Inst. Of Tech, 1995: stoker burners
		1.1	g/kg	Norway Inst. Of Tech, 1995: grate burners
Agricultural	15	0.74	g/kg	UNECE: Swedish data, 1.8-2 MW logging residue boilers
CHP	6	1.7	g/kg	Norway Inst. Of Tech, 1995: Fluidized bed
		3.3	g/kg	Norway Inst of Tech, 1995: Cyclone furnaces

The emission factor provided for NOx from domestic wood combustion in US EPA AP-42 is 1.3 kt/Mt wood burnt, approximately twice that currently used in the NAEI.

6.8 OXIDES OF SULPHUR

Only a single source of new data was identified for SO_2 emissions from wood combustion; the ERA Consulting report from 2000 [12] identified an emission factor of **0.03 g/kg** for wood combustion in a small commercial boiler.

The emissions of SO_X from all fuels across the small-scale combustion sector are dependent entirely on the sulphur content of the fuel source, and wood combustion is no different in that regard.

7 Petroleum-Based Oils and Gases

7.1 USE AND FUEL TYPES

A range of different fractions of crude oil are commonly used for the provision of heat and power across the UK, with the key fuel sources applicable to the small-scale combustion sector falling into the following categories:-

- Liquid Petroleum Gas (LPG: predominantly propane & butane)
- Burning Oil (light fuel oil, kerosene)
- Gas Oil (including diesel oil)
- Fuel Oil (heavier residual fuel oils)

Within the small-scale domestic sector the most commonly used fuel is Burning Oil and related light fuel oil fractions.

This study has investigated emission factor developments applicable to all of the above fractions, and the results are summarised here. Note that there was no new data found for gas oil use in any sub-sector of the small-scale combustion market. However, the differentiation between different petroleum oil fractions and the somewhat variable nomenclature employed around the world for these fractions is likely to be the main cause of this information gap.

In terms of volatility, gas oil sits between the lighter burning oil / kerosene fractions and the heavier fuel oil fractions. Where emission factor gaps exist for gas oil, comparison of the factors for burning oil and fuel oil is a reliable source of data for application to gas oil combustion.

The summary tables below outline the emission factor data identified for application to LPG, burning oil and fuel oil use in the small-scale combustion sector.

7.2 LIQUID PETROLEUM GAS

The following emission factors are currently used in the NAEI for combustion of LPG in small-scale combustion sectors:-

Sector	NO_X	VOC	CO	PM_{10}
	g/therm	g/therm	g/therm	g/therm
Domestic	4.9	0.194	0.86	0.39
Other Industry	9.4	0.194	0.25	0.29

The following table summarises CO, SO_2 and NO_X emission factors (and sources) for small-scale burning oil (kerosene) combustion, identified during this study:-

Sub-sector	REF.	Species	EF g/therm	Comment
Domestic open-fire	-	-	-	(no data identified specific to domestic open fires)
Domestic closed stove	24	CO	31.8	USEPA, 2000: developing world stove trials, LPG
		NMVOC	40.2	USEPA, 2000: developing world stove trials, LPG
Domestic Boiler	15	VOC	0.2	UNECE, 2002: dutch data, "domestic LPG use"
		SO_2	0.02	
		NO_X	4.2	
		CO	1.1	
		PM_{10}	0.2	
Commercial Boiler	9	VOC	0.5	BCC, 1998: UK data, LPG use in commercial appliances
Agricultural	15	VOC	0.2	UNECE, 2002: dutch data, "agricultural LPG use"
		SO_2	0.02	
		NO_X	4.2	
		CO	1.1	
		PM_{10}	0.2	
CHP	-	-	-	(no data identified specific to CHP)

7.3 BURNING OIL

7.3.1 NAEI emission factors

The NAEI uses the following emission factors for the combustion of burning oil in the small-scale combustion sector:

Sector	NO_X	VOC	CO	PM_{10}	PCDD/Fs
	g/kg	g/kg	g/kg	g/kg	g/Mt
Domestic	2.21	0.133	0.16	0.014	-
Public Service	2.84	0.086	0.16	0.014	-
Miscellaneous	2.84	0.086	0.16	0.014	-
Other Industry	2.84	0.086	0.16	0.014	4.3

The key target pollutants for which significant data was obtained include PM_{10} and VOCs, whilst some information was sourced regarding NO_X, CO and SO_2. No new data was sourced for PAH or dioxin and furan emissions.

7.3.2 PM_{10} Emission Factors

The following table summarises the PM_{10} emission factors (and sources) for small-scale burning oil (kerosene) combustion, identified during this study:-

Sub-sector	REF.	PM_{10} EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific this sector)
Domestic closed stove	2	0.05	g/kg	IIASA, 2001: German data, Domestic light fuel oil use
Domestic boiler	15	0.21	g/kg	UNECE, 2002: dutch data, "domestic oil use"
	2	1.4	g/kg	IIASA, 2001: EC figs, uncontrolled domestic boiler, light fuel oil
		0.01	g/kg	IIASA, 2001: German figs, uncontrolled domestic boiler, light fuel oil
		0.05	g/kg	RAINS, 2001: uncontrolled domestic boiler, light fuel oil
Commercial boiler	2	0.18	g/kg	IIASA, 2001: EC figs, uncontrolled industrial boiler, light fuel oil
		0.01	g/kg	IIASA, 2001: German figs, uncontrolled industrial boiler, light fuel oil
		0.05	g/kg	RAINS, 2001: uncontrolled industrial boiler, light fuel oil
Agricultural	15	0.21	g/kg	UNECE, 2002: dutch data, agricultural oil use
CHP	-	-	-	(no data identified specific to CHP)

7.3.3 VOC Emission Factors

The following table summarises the VOC emission factors (and sources) for small-scale burning oil (kerosene) combustion, identified during this study:-

Sub-sector	REF.	VOC EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to domestic open fires)
Domestic closed stove	24	14.9	g/kg	USEPA, 2000: developing world stove trials, kerosene wick, **NMVOC**
		19.2	g/kg	USEPA, 2000: developing world stove trials, kerosene pressure, **NMVOC**
Domestic boiler	15	0.7	g/kg	UNECE, 2002: dutch data, "domestic oil use", **total VOCs**
	9	0.7	g/kg	BCC, 1998: UK data, kerosene in domestic appliances, **total VOCs**
	16	0.07-0.35	g/kg	Rentz et al, 1998: oil-fired 35 kW boiler, benchmark / improved, **NMVOC**
Commercial boiler	16	0.05-0.23	g/kg	Rentz et al, 1998: oil-fired 200 kW boiler, benchmark / improved, **NMVOC**
Agricultural	15	0.46	g/kg	UNECE, 2002: dutch data, agricultural oil use
CHP	-	-	-	(no data identified specific to CHP)

7.3.4 CO, NO_X and SO_2 Emission Factors

The following table summarises CO, SO_2 and NO_X emission factors (and sources) for small-scale burning oil (kerosene) combustion, identified during this study:-

Sub-sector	REF.	Species	EF	Units	Comment
Domestic open-fire	-	-	-	-	(no data identified specific to domestic open fires)
Domestic closed stove	24	CO	17.7	g/kg	USEPA, 2000: developing world stove trials, kerosene wick
		CO	62.1	g/kg	USEPA, 2000: developing world stove trials, kerosene pressure
Domestic Boiler	15	SO_2	4	g/kg	UNECE, 2002: dutch data, "domestic oil use"
		NO_X	2.3	g/kg	
		CO	2.8	g/kg	
Commercial Boiler	-	-	-	-	(no data identified specific to commercial boilers)
Agricultural	15	SO_2	0.01	g/kg	UNECE, 2002: dutch data, "agricultural oil use"
		NO_X	2.3	g/kg	
		CO	0.5	g/kg	
CHP	-	-	-	-	(no data identified specific to CHP)

7.4 FUEL OIL

7.4.1 Current NAEI emission factors

The NAEI uses the following emission factors for the combustion of fuel oil in the small-scale combustion sector:

Sector	NO_X	VOC	CO	PM_{10}	PCDD/Fs
	g/kg	g/kg	g/kg	g/kg	g/Mt
Domestic	6.99	0.13	0.5	1.032	-
Agriculture	6.99	0.12	0.5	1.032	4.3
Public Service	6.99	0.12	0.5	1.032	-
Miscellaneous	6.99	0.12	0.5	1.032	-
Other Industry	7.54	0.12	0.5	1.032	4.3

The key target pollutants for which significant data was obtained include PM_{10} and VOCs, whilst some information was sourced regarding PAHs , benzene, NO_X, CO and SO_2. No new data was sourced for dioxin and furan emissions.

7.4.2 PM_{10} Emission Factors

The following table summarises the PM_{10} emission factors (and sources) for small-scale fuel oil combustion, identified during this study:-

Sub-sector	REF.	PM_{10} EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to these sectors)
Domestic closed stove	-	-	-	
Domestic boiler	2	2.2	g/kg	IIASA, 2001: EC figs, uncontrolled domestic boiler, heavy fuel oil
		0.3-1.2	g/kg	IIASA, 2001: German figs, uncontrolled domestic boiler, heavy fuel oil
		0.9	g/kg	RAINS, 2001: uncontrolled domestic boiler, heavy fuel oil
Commercial boiler	12	0.1	g/kg	ERA, 2000: domestic boiler, fuel oil #1
		0.8	g/kg	ERA, 2000: domestic boiler, fuel oil #4
		1.1	g/kg	ERA, 2000: domestic boiler, fuel oil #5
	2	0.1-0.6	g/kg	IIASA, 2001: German data, uncontrolled industrial heavy fuel oil use
		1	g/kg	IIASA, 2001: German data, uncontrolled industrial heavy fuel oil use in boilers
		0.9	g/kg	IIASA, 2001: EC data, uncontrolled industrial heavy fuel oil use
		0.65	g/kg	RAINS, 2001: uncontrolled industrial boiler, heavy fuel oil
Agricultural	-	-	-	(no data identified specific to these sectors)
CHP	-	-	-	

7.4.3 VOC Emission Factors

The following table summarises the VOC emission factors (and sources) for small-scale fuel oil combustion, identified during this study:-

Sub-sector	REF.	VOC EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to these sectors)
Domestic closed stove	-	-	-	
Domestic boiler	9	0.4	g/kg	BCC, 1998: UK data, residual fuel oil use in domestic appliances
Commercial boiler	12	0.03	g/kg	ERA, 2000: domestic boiler, fuel oil #1
		0.03	g/kg	ERA, 2000: domestic boiler, fuel oil #4
		0.04	g/kg	ERA, 2000: domestic boiler, fuel oil #5
	9	0.35	g/kg	BCC, 1998: UK data, residual fuel oil use in industry
Agricultural	-	-	-	(no data identified specific to this sector)
CHP	18	0.09	g/kg	1998: Australian data, fuel-oil fired power station, **NMVOC**
	9	0.30	g/kg	BCC, 1998; UK data, fuel oil use in power plant
	16	0.04	g/kg	Rentz et al, 1998: oil-fired 200kW boiler, improved and abated, **NMVOC**

7.4.4 PAH, benzene and toluene Emission Factors

The following table summarises the PAH, benzo(a)pyrene, benzene and toluene emission factors (and sources) for small-scale fuel oil combustion, identified during this study:-

Sub-sector	REF.	Species	EF	Units	Comment
Domestic open-fire	-	-	-	-	(no data identified specific to these sectors)
Domestic closed stove	-	-	-	-	
Domestic Boiler	20	B(a)P	3.4	g/T	Polish data: fuel oil use in residential sector
Commercial Boiler	22	B(a)P	22	g/KT	MSC-E, 2001: Russian data, low-capacity heat-power boilers
		B(a)P	13.2	g/KT	MSC-E, 2001: Russian data, water boilers
		B(a)P	4.3	g/KT	MSC-E, 2001: Russian data, heat-power boilers
	27	Benzene	0.57	g/T	VCAPCD, 2001: combustion of #1 & #2 fuel oil
		Toluene	0.57	g/T	
		PAHs	6.5	g/T	
Agricultural	20	B(a)P	3.4	g/T	Polish data: fuel oil use in agricultural sector
CHP	-	-	-	-	(no data identified specific to CHP)

7.4.5 CO, NO_X and SO_2 Emission Factors

The following table summarises the CO, NO_X and SO_2 emission factors (and sources) for small-scale fuel oil combustion, identified during this study:-

Sub-sector	REF.	Species	EF	Units	Comment
Domestic open-fire	-	-	-	-	(no data identified specific to these sectors)
Domestic closed stove	-	-	-	-	
Domestic Boiler	-	-	-	-	
Commercial Boiler	12	CO	0.7	g/kg	ERA, 2000: commercial boiler, fuel oil #1, 5% Sulphur
		NO_X	2.7	g/kg	
		SO_2	20	g/kg	
	12	CO	0.7	g/kg	ERA, 2000: commercial boiler, fuel oil #4, 5% Sulphur
		NO_X	2.7	g/kg	
		SO_2	20	g/kg	
	12	CO	0.7	g/kg	ERA, 2000: commercial boiler, fuel oil #5, 5% Sulphur
		NO_X	7.4	g/kg	
		SO_2	21	g/kg	
Agricultural	-	-	-	-	(no data identified specific to this sector)
CHP	18	NO_X	8.1	g/kg	1998: Australian data, fuel-oil fired power station
		CO	0.6	g/kg	

8 Natural Gas

8.1 FUEL USE

The fuel consumption figures for every sub-sector of the small-scale combustion market in the UK clearly indicate the importance that natural gas increasingly plays in this sector. Therefore, although natural gas is typically the cleanest fuel consumed in this sector, it is of key importance that the emission factors for gas combustion in the range of appliances across this sector are as accurate as possible.

8.2 NAEI EMISSION FACTORS

The NAEI uses the following emission factors for the combustion of natural gas in the small-scale combustion sector:

Sector	NO_X	CH_4	VOC	CO	PM_{10}
	kg/th	kg/th	kg/th	kg/th	kg/th
Domestic	0.00485	0.000285	0.000665	0.00086	0.000326
Agriculture	0.00488	0.00038	0.00038	0.00025	0.000326
Public Service	0.00488	0.00038	0.00038	0.00025	0.000326
Miscellaneous	0.00488	0.00038	0.00038	0.00025	0.000326
Other Industry	0.0095	0.00038	0.00038	0.00025	0.000326

A considerable amount of data and information pertaining to natural gas combustion has been considered, and the findings are summarised below.

8.3 PM_{10} EMISSION FACTORS

The following table summarises the PM_{10} emission factors (and sources) for small-scale natural combustion, identified during this study:-

Sub-sector	REF.	PM_{10} EF	Units	Comment
Domestic open-fire	-	-	-	(no data identified specific to this sector)
Domestic closed stove	2	0.00005	Kg/th	IIASA, 2001: German data, uncontrolled domestic gas furnaces
Domestic boiler	15	0.00003	Kg/th	UNECE. 2002: dutch data, domestic gas use
	12	0.0005	Kg/th	ERA, 2000: gas boiler EFs
	2	0.00002	Kg/th	IIASA, 2001: German data, uncontrolled domestic gas boilers
Commercial boiler	2	0.00001	Kg/th	IIASA, 2001: German data, uncontrolled industrial gas boilers
Agricultural	15	0.00002	Kg/th	UNECE. 2002: dutch data, agricultural gas use
CHP	-	-	-	(no data identified specific to this sector)

8.4 VOC EMISSION FACTORS

Sub-sector	REF.	VOC EF	Units	Comment
Domestic open-fire	28	0.0006	Kg/th	EMEP default figure for gas fireplaces, **NMVOC**
Domestic closed stove	28	0.0003	Kg/th	EMEP default figure for gas stoves, **NMVOC**
Domestic boiler	15	0.0007	Kg/th	UNECE. 2002: dutch data, domestic gas use
	12	0.0002	Kg/th	ERA, 2000: gas boiler EFs
	9	0.0005-0.0032	Kg/th	BCC, 1998: UK data, domestic gas appliances
	16	0.0003-0.0016	Kg/th	Rentz et al, 1998: 35kW boiler, improved-uncontrolled, **NMVOC**
Commercial boiler	9	0.0005	Kg/th	BCC, 1998: UK data, commercial gas appliances
	16	0.0001-0.0005	Kg/th	Rentz et al, 1998: 200 kW boiler, improved-uncontrolled, **NMVOC**
Agricultural	15	0.0032	Kg/th	UNECE. 2002: dutch data, agricultural gas use
CHP	18	0.0002	Kg/th	1998: Australian data, gas turbines, **NMVOC**
		0.00006	Kg/th	1998: Australian data, gas boilers, **NMVOC**
	9	0.00005	Kg/th	BCC, 1998: UK data, gas power plant
	16	0.0001	Kg/th	Rentz et al, 1998: 200 kW boiler, improved & abated, **NMVOC**
	29	0.0004	Kg/th	AEAT, 1998: gas CHP <20 MW, no NO_X control
		0.0017	Kg/th	AEAT, 1998: gas CHP <20 MW, with NO_X control
		0.0001	Kg/th	AEAT, 1998: gas CHP 20 – 40 MW, no NO_X control
		0.0003	Kg/th	AEAT, 1998: gas CHP 20 - 40 MW, with NO_X control

8.5 PAH, PCDD/F EMISSION FACTORS

The following table summarises the PAH, benzo(a)pyrene, benzene and PCDD/F emission factors (and sources) for small-scale gas combustion, identified during this study:-

Sub-sector	REF.	Species	EF	Units	Comment
Domestic open-fire	-	-	-	-	(no data identified specific to this sector)
Domestic closed stove	-	-	-	-	(no data identified specific to this sector)
Domestic Boiler	-	-	-	-	(no data identified specific to this sector)
Commercial Boiler	22	B(a)P	7.5	ug/th	MSC-E, 2001: Russian data, low-capacity heat-power boilers
		B(a)P	3.8	ug/th	MSC-E, 2001: Russian data, water boilers
		B(a)P	3.2	ug/th	MSC-E, 2001: Russian data, heat-power boilers
	27	Benzene	240	ug/th	VCAPCD, 2001: Gas-fired commercial boilers
		PAHs	20	ug/th	
	26	PAH	13	ug/th	USEPA, 1998: conventional gas furnace
		PAH	3	ug/th	USEPA, 1998: high efficiency gas furnace
Agricultural	-	-	-	-	(no data identified specific to these sectors)
CHP	-	-	-	-	

8.6 CARBON MONOXIDE

Sub-sector	REF.	CO EF	Units	Comment
Domestic open-fire	28	0.0021	Kg/th	EMEP default figure for gas fireplaces
Domestic closed stove	28	0.0011	Kg/th	EMEP default figure for gas stoves,
Domestic boiler	15	0.0017	Kg/th	UNECE. 2002: dutch data, domestic gas use
	12	0.0009	Kg/th	ERA, 2000: gas boiler EFs
Commercial boiler	-	-	-	(no data identified specific to this sector)
Agricultural	15	0.0011	Kg/th	UNECE. 2002: dutch data, agricultural gas use
CHP	18	0.0045	Kg/th	1998: Australian data, gas turbines,
		0.0020	Kg/th	1998: Australian data, gas boilers,
	29	0.0016-0.0044	Kg/th	AEAT, 1998: gas CHP <20 MW, no NO_X control
		0.0125	Kg/th	AEAT, 1998: gas CHP <20 MW, with NO_X control
		< 0.0002	Kg/th	AEAT, 1998: gas CHP 20 – 40 MW, no NO_X control
		0.0019	Kg/th	AEAT, 1998: gas CHP 20 - 40 MW, with NO_X control

8.7 OXIDES OF NITROGEN

Sub-sector	REF.	NO_X EF	Units	Comment
Domestic open-fire	28	0.0053	Kg/th	EMEP default figure for gas fireplaces
Domestic closed stove	28	0.0053	Kg/th	EMEP default figure for gas stoves,
Domestic boiler	15	0.0061	Kg/th	UNECE. 2002: dutch data, domestic gas use
	12	0.0042	Kg/th	ERA, 2000: gas boiler EFs
Commercial boiler	-	-	-	(no data identified specific to this sector)
Agricultural	15	0.0069	Kg/th	UNECE. 2002: dutch data, agricultural gas use
CHP	18	0.019	Kg/th	1998: Australian data, gas turbines,
		0.016	Kg/th	1998: Australian data, gas boilers,
	29	0.01-0.016	Kg/th	AEAT, 1998: gas CHP <20 MW, no NO_X control
		0.0037	Kg/th	AEAT, 1998: gas CHP <20 MW, with NO_X control
		0.017	Kg/th	AEAT, 1998: gas CHP 20 – 40 MW, no NO_X control
		0.008	Kg/th	AEAT, 1998: gas CHP 20 - 40 MW, with NO_X control

8.8 OXIDES OF SULPHUR

Sub-sector	REF.	SO_2 EF	Units	Comment
Domestic open-fire	28	0.00005	Kg/th	EMEP default figure for gas fireplaces
Domestic closed stove	28	0.00005	Kg/th	EMEP default figure for gas stoves,
Domestic boiler	15	0.00002	Kg/th	UNECE. 2002: dutch data, domestic gas use
	12	0.00002	Kg/th	ERA, 2000: gas boiler EFs
Commercial boiler	-	-	-	(no data identified specific to this sector)
Agricultural	15	0.00002	Kg/th	UNECE. 2002: dutch data, agricultural gas use
CHP	-	-	-	(no data identified specific to this sector)

9 Conclusions & Recommendations

9.1 OVERVIEW

The review of data and literature sources identified that the small combustion sector is a complex co-existing mix of different fuels and technologies which are also varying with time. The existing NAEI default emission factors for the sector exhibit a very limited data set. Consequently, the NAEI estimates of emissions from small combustion sources are considered to have significant areas of uncertainty.

Appendix C comprises a summary table of emission factors from sources identified within this study, and includes (for direct comparison), the equivalent factors from the USEPA AP-42 5th Edition and the NAEI 2001. The country of origin for the source of alternative emission factors is included, to give an indication of the applicability to the UK NAEI.

9.2 NAEI STRUCTURE FOR SMALL COMBUSTION SOURCES

The NAEI uses the fuel use activity statistics provided by the Digest of UK Energy Statistics (DUKES). The classifications used by DUKES cover a wide range of combustion processes and technologies, particularly for domestic combustion. However, the NAEI uses the same pollutant emission factors for several source categories. This study indicates that there is scope for improving the default emission factors in several source categories.

The NAEI contains a limited subset of emission factors and process classifications for small-scale combustion. These classifications are considered to be too broad and the necessary aggregation of emission factors is not immediately transparent. Aggregate emission factors are also of limited use for inventory users outside the NAEI.

In many instances (and in particular for domestic heating systems) further work is required to determine the relative fuel consumption between various heating technologies. For the purposes of this report, aggregated emission factors have been developed assuming equal fuel use across these technologies, but this is unlikely to be representative of the UK market.

Some progress has been made in identifying the trends regarding solid fuel use in different types of domestic appliance. The different appliances exhibit significantly different combustion profiles, and hence the assessment of the relative uses of the range of household appliances (broadly divided into: fireplaces, stoves and boilers) could be a significant source of error in the use of

NAEI data. Annual estimations for these sub-sectors of activity data are therefore recommended to provide a mechanism to calculate a more accurate emission factor that represents the whole of the domestic sector for each fuel.

Two approaches are suggested to improve estimation of small combustion plant emissions in the NAEI:

1. Expand the set of NAEI emission factors allowing a more complete mix of technologies and fuels to be represented.

2. Adopt a 'calculator' based approach whereby aggregate emission factors are calculated on the basis of fuel use, knowledge of the equipment 'pool', and the most up-to-date emission factor information. This approach allows development of the current most representative emission factor for use in the existing NAEI source classifications.

The latter approach maintains consistency with existing source classifications and would also allow a more transparent estimation of the aggregate emission factors perhaps as a separate tier to the structure of the NAEI. The separate tier or sub-inventory may be more readily modified or extended, as new information becomes available.

Expansion of the NAEI would keep all the information in a single inventory but increase the level of detail in the inventory and may make it a more unwieldy tool.

A review of the NAEI is recommended to determine the most appropriate approach.

9.3 INVENTORY COMBUSTION DATA PRIORITIES

9.3.1 Ranking by Fuel Consumption

The most significant sub-sectors for focussing of emission factor development efforts were identified as the following:-

Domestic Natural Gas use – this is the largest single sub-sector of fuel consumption.

Domestic Burning Oil use – the second most significant sub-sector in terms of energy use.

Commercial & Agricultural Burning Oil and Gas Oil use – the most significant fuels for these sub-sectors.

9.3.2 Ranking by Pollutant Emissions

The most significant fuels in terms of potential pollutant release are the solid fuels particularly in a domestic open fire.

Domestic Solid Fuel use – steam coal, anthracite, manufactured solid fuels and wood have wide variations in their combustion properties. In addition, the lack of combustion controls or abatement on domestic-scale solid fuel space-heating sources and the variability of combustion efficiency of domestic fireplaces and stoves provides a potentially significant source of Products of Incomplete Combustion. Therefore, whilst consumption of these fuels may be much lower than gas or oil, their contributions to total emissions of species such as CO, VOC, PM_{10} and PAHs may nevertheless be significant.

Burning, Fuel and Gas Oils – Combustion of these fuels is inherently less polluting than a solid fuel but can give rise to significant emission of PM_{10}, CO, VOC and other emissions.

9.4 AVAILABILITY AND ACCURACY OF DATA

Across the small-scale combustion sector, the amount of available emissions data for different fuels and appliances is very limited. Improvement of the existing NAEI data has been hindered by the following:-

- This study has identified very little new emission data specific to UK combustion processes, although in many cases the emissions data sourced from overseas may be considered representative of the UK.
- No comprehensive profile of UK small-scale combustion sub-sectors exist that describe fuel consumption or pollutant emissions.
- In several cases, separate research into similar combustion processes have produced pollutant emission factors that are extremely variable (over two orders of magnitude difference in some instances).
- In addition to process variations, research studies employ different measurement methodologies (application of ISO, EN or National emission measurement standards is rare), reporting units are inconsistent and uncertainty data are not available. Consequently the uncertainty of the reported measurement data is often unknown.

9.5 DOMESTIC COMBUSTION OF NATURAL GAS

In general, the emission factors used in the NAEI show correspond reasonably well with the emission factors gathered for this study.

Domestic Sector	NO_X	CH_4	VOC	CO	PM_{10}
	kg/th	kg/th	kg/th	kg/th	kg/th
NAEI	0.00485	0.000285	0.000665	0.00086	0.00033
Proposed factor	-	-	-	0.0015	0.00002
Comment	No change	No change	No change	Increase	Decrease

- The **PM_{10}** emission factor in the NAEI is currently 0.00033 kg/th for domestic gas combustion. This is consistent with the recent report from ERA Consulting [12], but is an order of magnitude higher than dutch and german emission

factors which range from 0.00002-0.00005 kg/th. A lower factor is proposed but this anomaly warrants further investigation.

- The **CO** emission factor in the NAEI is currently 0.00086 kg/th for domestic gas combustion. Recent UK and european research indicate that this figure is low. Although the NAEI figure is consistent with the ERA Consulting report from 2000 [12] which determined the CO factor to be 0.0009 kg/th, dutch data from the UNECE and EMEP-sourced emission factors range from 0.0011 to 0.0021 kg/th.

9.6 DOMESTIC COMBUSTION OF SOLID FUELS

Domestic Solid Fuel Sector	NO_X g/kg	VOC g/kg	CO g/kg	PM_{10} g/kg	BaP kg/Mt	PCDD/F g/Mt
Coal :						
NAEI	1.42	14	45	10.4	1550	3.04
Proposed factor	5	9	190	-	-	4
Comment	Increase	Decrease	Increase	No change	Limited data	Increase
Coke :						
NAEI	1.33	4.9	45	0.29	30	2.4
Proposed factor	9	3	750	2	-	-
Comment	Increase	Decrease	Increase	Increase	No data	No data
Anthracite :						
NAEI	1.6	1.7	45	3.6	30	2.1
Proposed factor	9	3	750	2	-	2.4
Comment	No emission data for anthracite in domestic furnaces – treated as coke					
SSF :						
NAEI	1.32	4.9	45	5.6	330	2.7
Proposed factor	3	-	710	1	-	-
Comment	Increase	No change	Increase	Decrease	No data	No data
Wood :						
NAEI	0.72	5.42	99	7.9	1300	0.24
Proposed factor	0.8	7	50	3	-	-
Comment	Increase	Increase	Decrease	Decrease	Limited data	No data

9.6.1 Coal

- The range of studies on **PM_{10}** emissions from domestic coal combustion appliances illustrate that results from open fire burning are extremely variable, but that the current NAEI figure of 10.4 g/kg is consistent with the average figure determined by recent trials.

  In contrast, studies from across the UK and Europe indicate that the burning

of coal in closed stoves and domestic boilers is a more uniform process with significantly less variability on emission factors determined. On the whole, the emission factors for stoves and boilers are consistently found to be 3-6 g/kg. The current NAEI figure is therefore not representative of these types of appliance.

Further information on the types of fire in use is required to develop an improved aggregate PM_{10} emission factor.

- The current NAEI **NO_x** emission factor of 1.42 g/kg, is lower than data collated from UK and european sources which indicate that NO_X values of 2-8 g/kg are characteristic for residential coal use. An increase in the default emission factor to 5 g NO_2 per kg is proposed. However, as for PM_{10}, a clearer picture of the use of coal across open fires, closed stoves and boilers would improve the estimate of the NO_X figure.

- There is relatively little consistent data regarding **CO** emissions from domestic coal combustion sources however, the available suggest an increase in the aggregate factor to 190 g/kg.

- The emission of **VOC** from combustion sources often shows similar variation to CO and it is surprising to find that the VOC data are less variable than the CO data. Although there are limits to the VOC data (the definitions and expression are inconsistent) the data sources indicate a decrease in the aggregate emission factor.

- Emission factors for VOC and CO for domestic coal combustion are considered to have a particularly high uncertainty.

- The emission data suggest an increase in the aggregate dioxins emission factor is required.

9.6.2 Coke, Anthracite

- No data were obtained for anthracite combustion and **netcen** has assumed similar combustion properties to coke.

- A UK-focused study into domestic coal burning [13] reported **PM_{10}** emission factors for the burning of coke in the domestic sector both on open fires and in closed appliances. This study shows PM_{10} emissions from coke burning on domestic fires (both for open appliances and closed stoves) to be substantially higher than that currently used in the NAEI. It is therefore recommended that the PM_{10} emission factors from domestic coke combustion in the NAEI be increased to 2 kg/tonne.

- An increase in the **NO_x** emission factor is also proposed based on factors of 7 and 11 g NO_2 per kg reported by CRE and UNECE for coke stove and domestic boiler respectively. However, no information was found for open fires and the proposed factor may overestimate emissions from domestic open fires.

- The CRE and UNECE studies reported **CO** emission factors very much higher than the NAEI default factor and a higher aggregate emission factor of 750 g/kg is proposed. This is a similar order of magnitude as the aggregate factor for coal combustion, and is the mean factor derived from a very wide array of reported factors from sources identified (ranging from 120 to 1200 g/kg).

- No emission data were obtained for dioxins and Benz(a)pyrene for domestic coke or anthracite combustion.

- A decrease in the **VOC** emission factor for Coke is proposed but application of the same factor to Anthracite results in an increase in the aggregated factor.

9.6.3 Manufactured Solid Fuels

- A reduction of the **PM_{10}** emission factor is proposed which is consistent with the application of these fuels as smokeless fuels. A number of sources report consistent factors of around 1 g/kg.

- An increase in the **NO_x** emission factor is also suggested based on reported factors but the increase is not consistent with the increase in factors reported for Coke.

- The reported **CO** emission factors were extremely variable and did not include combustion on an open fire. Nonetheless the aggregate CO emission factor is still over an order of magnitude higher than the NAEI default factor. The aggregate factor is consistent with the other proposed aggregate emission factor for coal and coke.

- No emission data were obtained for dioxins and Benz(a)pyrene for domestic combustion of manufactured solid fuel.

- Regarding **VOC** emission factors for MSF use, only a single swedish source provided any additional data relevant to the UK market, quoting a range of figures from 0.3-7.7 g/kg. As this is consistent with the current NAEI figure of 4.9 g/kg, no alteration is recommended.

9.6.4 Wood

- Wood combustion emission data is generally based on US or Norwegian emission surveys and may not be applicable to UK domestic combustion practise and UK supply of wood fuel.

- From the data obtained, a reduction of the **PM_{10}** emission factor to around 3 g/kg is recommended. Whilst the current NAEI figure is consistent with UK data for wood burning on open fires, all other UK and european-sourced data provides lower PM_{10} figures, particularly for wood burning on closed stoves and in boilers.

- A very minor increase in the **NO_X** emission factor is also suggested based on reported factors ranging from 0.3 to 1.0 g/kg.

- The reported **CO** emission factors were surprisingly consistent across the various combustion appliances and indicate a reduction in the aggregate emission factor.

- The reported **VOC** emission factors were also quite consistent across the various combustion appliances, ranging from 1 to 17.5 g/kg. An aggregate emission factor of 7g/kg is recommended from the UK, Norwegian and German data sourced in this study.

- No emission data were obtained for dioxins. PAH and Benz(a)pyrene data are published but are limited and are not expressed consistently. Consequently no change is proposed to the current default factors however, a more detailed review of the source data could provide data.

9.7 COMBUSTION OF OILS

9.7.1 Burning oil

Activity	NO_X	VOC	CO	PM_{10}	BaP	PCDD/F
	g/kg	g/kg	g/kg	g/kg	kg/Mt	g TEQ/Mt
Domestic						
NAEI	2.21	0.133	0.16	0.014	-	-
Proposed factor	2.31	0.5	1.8	0.34	4.3	0.2
Comment	Increase	Increase	Increase	Increase	Corinair small-scale combustion default	
Public						
NAEI	2.84	0.086	0.16	0.014	-	-
Proposed factor	-	0.14	-	0.08	4.3	0.2
Comment	No data	Increase	No data	Increase	Corinair small-scale combustion default	
Commercial/Industrial						
NAEI	2.84	0.086	0.16	0.014	-	4.3
Proposed factor	-	0.14	-	0.08	4.3	0.2
Comment	Proposed factors for Public, Institutional boilers					
Agricultural						
NAEI	-	-	-	-	-	-
Proposed factor	2.31	0.46	0.46	0.21	4.3	0.2
Comment	Dutch data				Corinair small-scale combustion default	

For the domestic sector:-

- A single dutch figure of 2.31 g/kg was sourced for **NO_X** emissions.

- Sources of UK, dutch and german data were found to be very consistent for **VOC** emissions, and an aggregate factor of 0.5 g/kg is recommended.

- Limited data was identified regarding **CO** emissions. The aggregate from dutch and american sources provides the figure of 1.8 g/kg.

- An aggregate figure of 0.34 g/kg derived from dutch, german and american sources is recommended for **PM_{10}** emissions for domestic combustion of burning oil.

For the public & commercial / industrial sectors, only limited data from german sources was obtained pertaining to **VOC** and **PM_{10}** emission factors, and in both cases these data suggest that the current NAEI figure ought to be increased slightly.

No factors currently exist in the NAEI for agricultural burning oil combustion. A single source of dutch data was identified, and emission factors from this source are proposed for each pollutant.

9.7.2 Other oils :

Note that almost all of the source data summarised in the following table are actually for heavier fuel oils. The applicability to gas oil is not known. Combustion conditions are broadly comparable but the fuel characteristics are very different.

Very little information has been sourced pertaining precisely to gas oil use, but many factors from fuel oil are estimated to be representative of gas oil use.

- Emission factor data for fuel oil use across all sectors would suggest that a figure of 1 g/kg may be a reliable estimate for a **PM_{10}** emission factor gas oil use.

- UK & AP-42 **VOC** emission factor data for fuel oil use across all sectors would suggest that figures of around 0.2 g/kg (Public, commercial and industrial sectors) and 0.1 g/kg (agricultural and CHP) may be reliable estimates for gas oil use.

- UK & AP-42 **CO** data for fuel oil use across all sectors would suggest that figures of around 0.7 g/kg may be a more reliable estimate for gas oil use than the current NAEI estimate.

Activity	NO_X	VOC	CO	PM_{10}	BaP	PCDD/F
	g/kg	g/kg	g/kg	g/kg	kg/Mt	g TEQ/Mt
Domestic						
NAEI (gas oil)	*2.16*	*0.13*	*0.24*	*0.25*	-	-
NAEI (fuel oil)	7.0	0.13	0.5	1.0	-	-
Proposed factor	-	0.4	-	1.4	4.3	0.2
Comment	No data	Increase	No data	Increase	Corinair small-scale combustion default	
Public						
NAEI (gas oil)	*2.84*	*0.086*	*0.24*	*0.25*	-	-
NAEI (fuel oil)	7.0	0.12	0.5	1.0	-	-
Proposed factor	6	0.2	0.7	1	4.3	0.2
Comment	Decrease	Increase	Increase	No change	Corinair small-scale combustion default	
Commercial/Industrial						
NAEI (gas oil)	*3.46*	*0.086*	*0.24*	*0.25*	*4.7*	*4.3*
NAEI (fuel oil)	7.5	0.12	0.5	1.0	4.3	4.7
Proposed factor	4.3	0.12	0.7	0.7	4.3	0.2
Comment	Decrease	No change	Increase	Decrease	Corinair small-scale combustion default	
Agricultural						
NAEI (gas oil)	*2.84*	*0.13*	*0.71*	*0.25*	*4.7*	*4.3*
NAEI (Fuel oil)	7.0	0.12	0.5	1.0	4.7	4.3
Proposed factor	-	-	-	-	3.4	0.2
Comment	No data				Polish data	Corinair default

9.7.3 Domestic and Public & Commercial Combustion of LPG

Apart from VOC emissions, no UK-focussed research has been identified pertaining to LPG combustion. This fuel only accounts for 1.7% of total GWh production across the small-scale combustion sector, however, and with the exception of VOC, is likely to demonstrate emissions similar to those of natural gas.

In the absence of source data, the emission factors proposed for natural gas provide a sound estimate.

9.8 OTHER AREAS RECOMMENDED FOR FURTHER STUDY

Areas of uncertainty that warrant more investigation including :-

- **Activity data** – Significant disparity in UK coal consumption is evident between the DUKES data and industry-sourced figures. There may be an end-

user group as yet unrepresented, or mis-represented, within the current NAEI data.

- **CHP technology** – This study has identified that there are four or five main technological options for small-scale CHP installations. Although technology based on gas-fired gas turbines has the greatest share of the market; other fuels and technologies also make a significant contribution to CHP generation and may exhibit very different emission profiles. A greater understanding of the variability of emissions from these CHP technologies would be a significant step in improving the quality of NAEI data for this growing sector.

A potential source of emission data research on small-scale combustion (and other sources) is via the national programmes of other countries and co-operative international emission inventory work programmes at UN ECE or EU level. Emissions from residential and other small-scale combustion sources are a common area of concern; it is known that work is being undertaken in several EU member States and the EC's Joint Research Centre, Emissions and Health Unit, has in place a work programme to co-ordinate this activity and encourage the exchange of information.

However, emission data from sources outside the UK are of little use to development of the NAEI if the source measurements are for combustion technologies or fuels which are not employed in the UK. To improve inventory uncertainty emission data should, wherever possible, be obtained from accredited test houses using recognised test protocols (for example EN or ISO Standards).

9.9 IMPACT OF RESEARCH ON INVENTORY QUALITY

The research detailed in this report is the first stage of a process of improvement of a major source of air pollution - small combustion plant. At this stage it is not possible to quantify exactly how much emission estimates will change as a result of this work since much remains to be done, either extending the level of detail in the NAEI or producing an 'emissions caclulator'. The approaches recommended in this report could also be extended to medium sized combustion plant i.e. plant upto 50MWth in size leading to further, as yet, unquantified improvements in inventory quality. This would also help to improve estimates for large combustion plant since, if these plant were treated separately in the NAEI, then emissions data for these plant, reported by the Environment Agency, Scottish Environment Protection Agency and DOE (Northern Ireland) could be used as the basis of estimates for these sites. The work started with this report could have far-reaching and significant impacts on the quality of the NAEI.

For the moment, some indication of the scale of change in the NAEI that might occur as a result of this process, can be derived by examining the change in emission totals that would occur if emissions from small combustion were estimated using emission factors recommended in this report rather than current NAEI emission factors.

Pollutant	Change	National total	% change
Carbon monoxide	+ 1303 ktonnes	3758 ktonnes	+35%
Oxides of nitrogen	+17 ktonnes	1681 ktonnes	+1%
VOC	- 3 ktonnes	1514 ktonnes	0%
PM_{10}	- 12 ktonnes	191 ktonnes	-6%
B[a]P	+ 0.02 tonnes	10.47 tonnes	0%
Dioxins	- 9 grammes	357 grammes	-2%

The changes shown in this table are based on a simple substitution of one set of emission factors for another, rather than the radical overhaul of the estimation methodology used in the NAEI for combustion sources that has been recommended here. The figures given can therefore only be a guide but suggest that, for certain pollutants such as carbon monoxide and PM_{10} and, to a lesser extent NOx and dioxins, this research could lead to major changes in national emission totals.

10 References

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Appendices

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Appendix A

Fuel Consumption by Sector

Table A1: ***Total GWh consumption of fuels by sector (2001: DUKES figures)***

	Domestic	Public	Commercial	Industry	PC&I	Agriculture	Miscellaneous	Total (fuel)
Steam coal	12138	1071	51		1122	43	86	13389
anthracite	9142	0	0		0	0	0	9142
Manuf. Solid fuel	4069	0	0		0	0	0	4069
wood	2373	0	0		0	0	0	2373
renewables	0	0	1396		1396	837	0	2233
propane	3514	0	5250	2736	7986	1514	0	13014
butane	876	0	849	849	1698	14	0	2588
kerosene	34974	158	0	20617	20775	158	0	55907
gas oil	2387	8338	4973		13311	5542	1348	22588
fuel oil	71	475	403		878	131	214	1294
natural gas	379200	45500	36500		82000	1300	28200	490700
total (sector)	448744	55542	49422	24202	129166	9539	29848	617297

Table A2 Sector distribution of fuel consumption as percentage of total consumption in small combustion sector

	Domestic	PCI	Agriculture	Miscellaneous	Total (fuel)
Steam coal	**2.0**	0.2	0.0	0.0	2.2
anthracite	**1.5**	0.0	0.0	0.0	1.5
Manuf. Solid fuel	**0.7**	0.0	0.0	0.0	0.7
wood	**0.4**	0.0	0.0	0.0	0.4
renewables	0.0	0.2	0.1	0.0	0.4
propane	**0.6**	**1.3**	0.2	0.0	2.1
butane	0.1	0.3	0.0	0.0	0.4
kerosene	**5.7**	**3.4**	0.0	0.0	9.1
gas oil	0.4	**2.2**	**0.9**	0.2	3.7
fuel oil	0.0	0.1	0.0	0.0	0.2
natural gas	**61.4**	**13.3**	0.2	**4.6**	79.5
total (sector)	72.7	20.9	1.5	4.8	100.0

Table A3: ***Sectoral Summaries of fuel consumption, as %age of total sector consumption in GWh***

	Domestic	% domestic
Steam coal	12138	3
anthracite	9142	2
Manuf. Solid fuel	4069	1
wood	2373	1
renewables	0	0
propane	3514	1
butane	876	0
kerosene	34974	8
gas oil	2387	1
fuel oil	71	0
natural gas	379200	85
total (sector)	448744	

	Public, Commercial, Industrial	% PCI
Steam coal	1122	1
anthracite	0	0
anuf. Solid fuel	0	0
wood	0	0
renewables	1396	1
propane	7986	6
butane	1698	1
kerosene	20775	16
gas oil	13311	10
fuel oil	878	1
natural gas	82000	63
total (sector)	129166	

	Agriculture	% agric
Steam coal	43	0.5
anthracite	0	0
Manuf. Solid fuel	0	0
wood	0	0
renewables	837	9
propane	1514	16
butane	14	0.1
kerosene	158	2
gas oil	5542	58
fuel oil	131	1
natural gas	1300	14
total (sector)	9539	

	Misc	%Misc
Steam coal	86	0.3
anthracite	0	0
Manuf. Solid fuel	0	0
wood	0	0
renewables	0	0
propane	0	0
butane	0	0
kerosene	0	0
gas oil	1348	5
fuel oil	214	1
natural gas	28200	94
total (sector)	29848	

Appendix B

Summary of Emission Factors and Information Sources, sorted by Fuel

Table B1: Summary of Source Reference Documents for EF Information

FUEL =>	Coal		Gas	Burning Oil & Gas Oil	Fuel Oils		Wood		SSF	Renewables
COMBUSTION UNIT TYPE										
Domestic Open Fire	5, 6, 7, 18 21, 28, 29	(11,)	7, 11, 14		14	29	5, 7, 9, 11 17, 21, 22 23, 27, 28	(12, 26)	6, 7, 11 29	26
Domestic closed stove	6, 7, 11,18 21, 28, 29	(4, 5)	7, 11, 14 27	11	14, 18, 27	(11,29)	7, 9, 11 17, 18, 21 22, 23, 27	5, 12, 26 28	6, 7, 11 18 29	26
Domestic Boiler	4, 7, 11 16, 18 21, 28, 29	(5, 6)	7, 11, 14 16, 18, 27	11	14, 16, 18 27	(11, 29)	7,9,11,12 16, 17, 18 21, 22, 23 27, 28	(5,)	6, 7, 11 18 29	11
Small commercial or institutional boiler	4, 7, 11 16, 18 21, 28, 29	(5, 6)	7, 11, 14 16, 18, 27	11	14, 16, 18 27	(11, 29)	7,9,11,12 16, 18, 21 27, 28	(5, 17)	6, 7 29	11
Agricultural Heater	4, 7, 11 16, 18, 29	(5,6)	7, 11, 14 16, 18	11	14, 16, 18	(11, 29)	7, 9, 12 16, 18	5, 17+Q41	6, 7 29	
CHP **a) steam turbine (ST)** **b) gas turbine (GT)** **c) comb. Cycle (CC)** **d) recipr. Engine (RE)** **e) condensing ST (CST)**	11, 13, 16 18, 29	(10,)	11, 13, 14 16, 18	11	13, 14, 16		16, 18			11

Table B2: DUKES figures
(2001 consumption)

FUEL =>	Coal	Gas	Propane	Butane	Burning Oil	Gas Oil	Fuel Oils	Wood	SSF	Renewable	Other CHP
COMBUSTION UNIT TYPE											
Total domestic	2536000 tonnes 95 %coal 21573 GWh	77 %gas 379000 Gwh	253000 tonnes 34 %prop 3514 GWh	64000 tonnes 50 %but 676 Gwh	2640000 tonnes 100 %ko 34974 GWh	193000 tonnes 11 %go 2387 Gwh	6000 tonnes 5 % 71 GWh	204000 t oil equiv 100 % 2373 Gwh	513000 tonnes 100 % 4069 GWh		
Small commercial or institutional boiler	126000 tonnes 5 %coal 1071 GWh	17 %gas 82000 Gwh	378000 tonnes 51 %prop 5250 GWh	62000 tonnes 49 %but 849 Gwh	12000 tonnes 158 GWh	1076000 tonnes 59 %go 13310 Gwh	73000 tonnes 68 % 866 GWh			120000 t oil equiv 1396 GWh	
Industry Space Heating			197000 tonnes 2736 GWh	62000 tonnes 849 Gwh	1561000 tonnes 20617 GWh	3384000 tonnes 41881 GWh	743000 tonnes 8816 GWh				
Agricultural Heater	0 tonnes 0 %	0.3 %gas 1300 Gwh	109000 tonnes 15 %prop 1514 GWh	1000 tonnes 1 %but 14 Gwh		449000 tonnes 25 %go 5542 Gwh	11000 tonnes 10 % 131 GWh			72000 t oil equiv 837 GWh	
CHP	7256 GWh 6 % totCHI	68804 GWh 61 %totCHP					8066 GWh 7 %totCHP			2224 GWh 2 %totCHP	35703 GWh 24 %totCHP
a) steam turbine (ST)	31 %coal	8 %gas					7 %fuel oil			0 %renew	18 % other
b) gas turbine (GT)	0 %coal	19 %gas					5 %fuel oil			1 %renew	5 % other
c) comb. Cycle (CC)	4 %coal	54 %gas					74 %fuel oil			1 %renew	28 % other
d) recipr. Engine (RE)	0 %coal	12 %gas					2 %fuel oil			71 %renew	0 % other
e) condensing ST (CST)	65 %coal	6 %gas					12 %fuel oil			27 %renew	48 % other
"Miscellaneous"		28000 Gwh 7 %				109000 tonnes 17 % 1348 GWh	10000 tonnes 17 % 214 GWh				

Table B3: COAL EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire	6	CRE PM10 research: open fire, < 10 kW, household coal (bit)	PM10	9	g/kg		
	6	CRE PM10 research: open fire, < 10 kW, texan star coal (bit)	PM10	11	g/kg		
	5	CPL Research: open fire, < 5kW, yorkshire housecoal (bit)	PCDDs	0.72	gTEQ/MT		
	5	CPL Research: open fire, < 5kW, yorkshire housecoal (bit)	PCDFs	2.2	gTEQ/MT		
	5	CPL Research: open fire, < 5kW, yorkshire housecoal (bit)	PCBs	6.1	gTEF/MT		
	5	CPL Research: open fire, < 5kW, yorkshire housecoal (bit)	PCNs	0.68	kg/MT		
	5	CPL Research: open fire, < 5kW, yorkshire housecoal (bit)	33 PAHs	0.254	g/kg		
	5	CPL Research: open fire, < 5kW, yorkshire housecoal (bit)	PM10	40.4	g/kg		
	29	BCC Research: domestic open grate, bituminous coal	NMVOC	14	g/kg		
	29	BCC Research: domestic open grate, bituminous coal	CH4	15.7	g/kg		
Domestic closed stove	11	UNECE TFEIP: Dutch data for domestic coal use	VOC	60	g/GJ	1.9	g/kg
	11	UNECE TFEIP: Dutch data for domestic coal use	SO2	420	g/GJ	13.0	g/kg
	11	UNECE TFEIP: Dutch data for domestic coal use	NOX	75	g/GJ	2.3	g/kg
	11	UNECE TFEIP: Dutch data for domestic coal use	CO	1500	g/GJ	46.4	g/kg
	11	UNECE TFEIP: Dutch data for domestic coal use	PM10	120	g/GJ	3.7	g/kg
	28	CRE: Uk 12.5 kW roomheater, anthracite, medium burn rate	CO	709	g/kg		
	28	CRE: Uk 12.5 kW roomheater, anthracite, medium burn rate	SO2	104	g/kg		
	28	CRE: Uk 12.5 kW roomheater, anthracite, medium burn rate	NOX	8	g/kg		
	19	IIASA: German figs for uncontrolled domestic coal furnace	PM10	110	g/GJ	3.4	g/kg
Domestic Boiler	11	UNECE TFEIP: Polish figs for various coals in 50kW and 150kW stoves. CO, SO2, NO2, VOC, PAHs, PCDD/Fs					
	16	ERA research: Boiler Efs, bituminous coal	CO	1.8	g/kg		
	16	ERA research: Boiler Efs, bituminous coal	NOX	6.2	g/kg		
	16	ERA research: Boiler Efs, bituminous coal	PM10	6	g/kg		
Domestic Boiler	16	ERA research: Boiler Efs, bituminous coal	SOX	17.2	g/kg		
	16	ERA research: Boiler Efs, bituminous coal	VOC	0.02	g/kg		
	29	BCC Research: 17 kW underfeed, bituminous coal	NMVOC	0.61	g/kg		
	29	BCC Research: 17 kW underfeed, bituminous coal	CH4	0.43	g/kg		
	29	BCC Research: 13 kW gravity feed, anthracite	NMVOC	1.7	g/kg		
	29	BCC Research: 13 kW gravity feed, anthracite	CH4	2	g/kg		
	34	Rentz et al: hard coal, 35 (0-120) kW boiler, benchmark	NMVOC	195	g/GJ	6.0	g/kg
	34	Rentz et al: hard coal, 35 (0-120) kW boiler, improved	NMVOC	40	g/GJ	1.2	g/kg
	34	Rentz et al: brown coal, 35 (0-120) kW boiler, benchmark	NMVOC	380	g/GJ	12.9	g/kg
	34	Rentz et al: brown coal, 35 (0-120) kW boiler, improved	NMVOC	76	g/GJ	2.6	g/kg
	19	IIASA: German figs for uncontrolled domestic coal boilers	PM10	90	g/GJ	2.8	g/kg
	33	Poland: residential use of hard coal	BaP	1.5	kg/Mt		
	33	Poland: residential use of brown coal	BaP	0.9	kg/Mt		
	7	EMEP/CORINAIR default figs: small-scale coal combustion	PCDD/Fs	1-2.5	ugTEQ/t		
	7	EMEP/CORINAIR default figs: small-scale coal combustion	BaP	0.6-2.0	g/t		
	36	Russian POPs data: residential	BaP	0.1	g/tonne		
Small commercial or institutional boiler	18	MSC-E research: russian low capacity heat-power boilers	BaP	13-56	mg/tonne		
	18	MSC-E research: russian heat-power boilers	BaP	9.2	mg/tonne		
	4	AEAT research: bituminous coal-fired boiler, rated 500kW	BaP	2.3	kg/Mt		
	4	AEAT research: bituminous coal-fired boiler, rated 500kW	benzene	< 0.01	kt/Mt		
	4	AEAT research: bituminous coal-fired boiler, rated 500kW	CO	10	kt/Mt		
	4	AEAT research: bituminous coal-fired boiler, rated 500kW	PCDD/Fs	51	gITEQ/Mt		
	4	AEAT research: bituminous coal-fired boiler, rated 500kW	33 PAHs	1650	ug/kg		
	29	BCC Research: 0.9 - 48 MW boilers, bituminous coal	NMVOC	0.05	g/kg		
	29	BCC Research: 0.9 - 48 MW boilers, bituminous coal	CH4	0.01	g/kg		
	34	Rentz et al: hard coal, 200 (120-300) kW boiler, benchmark	NMVOC	30	g/GJ	0.9	g/kg
	34	Rentz et al: hard coal, 200 (120-300) kW boiler, improved	NMVOC	6	g/GJ	0.2	g/kg
	34	Rentz et al: brown coal, 200 (120-300) kW boiler, benchmark	NMVOC	30	g/GJ	1.0	g/kg

Table B4: MANUFACTURED SOLID FUELS EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire	6	CRE research: open fire, < 10 kW, smokeless coal brands	PM10	0.9 - 1.6	g/kg		
	6	CRE PM10 research: open fire, < 10 kW, pet coke blends	PM10	2.3 - 2.8	g/kg		
	29	BCC Research: domestic coke use	VOC	5.0 - 20	g/GJ	0.15-0.60	g/kg
Domestic closed stove	26	USEPA: fuel use in developing world home stoves, charcoal	CO	275	g/kg		
	26	USEPA: fuel use in developing world home stoves, charcoal	TNMOC	10.5	g/kg		
	26	USEPA: fuel use in developing world home stoves, charcoal	TSP	2.4	g/kg		
	26	USEPA: fuel use in developing world home stoves, charbriq.	CO	121	g/kg		
	26	USEPA: fuel use in developing world home stoves, charbriq.	TNMOC	16.1	g/kg		
	26	USEPA: fuel use in developing world home stoves, charbriq.	TSP	2.9	g/kg		
	6	CRE research: closed stove, < 10 kW, smokeless coal brands	PM10	1.0-1.2	g/kg		
	6	CRE PM10 research: closed stove, < 10 kW, pet coke blends	PM10	2.6-3.2	g/kg		
	28	CRE: Uk 12.5 kW roomheater, coke, medium burn rate	CO	1125	g/kg		
	28	CRE: Uk 12.5 kW roomheater, coke, medium burn rate	SO2	127	g/kg		
	28	CRE: Uk 12.5 kW roomheater, coke, medium burn rate	NOX	7	g/kg		
	28	CRE: Uk 12.5 kW roomheater, manuf briq, medium burn rate	CO	1193	g/kg		
	28	CRE: Uk 12.5 kW roomheater, manuf briq, medium burn rate	SO2	75	g/kg		
	28	CRE: Uk 12.5 kW roomheater, manuf briq, medium burn rate	NOX	4	g/kg		
Domestic Boiler	11	UNECE TFEIP: dutch figures for coke use	VOC	91	g/GJ	2.7	g/kg
	11	UNECE TFEIP: dutch figures for coke use	SO2	371	g/GJ	11.1	g/kg
	11	UNECE TFEIP: dutch figures for coke use	NOX	382	g/GJ	11.4	g/kg
	11	UNECE TFEIP: dutch figures for coke use	CO	12400	g/GJ	369.5	g/kg
	11	UNECE TFEIP: dutch figures for coke use	PM10	6	g/GJ	0.2	g/kg
	11	UNECE TFEIP: sweden, pellet boilers 3-6 kW	TSP	15-65	g/GJ	0.5-2.0	g/kg
	11	UNECE TFEIP: sweden, pellet boilers 3-6 kW	THC	10-250	g/GJ	0.3-7.7	g/kg
Domestic Boiler	11	UNECE TFEIP: sweden, pellet boilers 3-6 kW	NOX	64-73	g/GJ	2.0-2.2	g/kg
	11	UNECE TFEIP: sweden, pellet boilers 1.8-2 MW	TSP	32-43	g/GJ	1.0-1.3	g/kg
	11	UNECE TFEIP: sweden, pellet boilers 1.8-2 MW	THC	0-500	g/GJ	0-15	g/kg
	11	UNECE TFEIP: sweden, pellet boilers 1.8-2 MW	NOX	17-37	g/GJ	0.5-1.1	g/kg
	11	UNECE TFEIP: sweden, pellet boilers 1.8-2 MW	CO	140-7400	g/GJ	4-226	g/kg
	34	Rentz et al: coke, 35 (0-120) kW boiler, benchmark	NMVOC	220	g/GJ	6.6	g/kg
	34	Rentz et al: coke, 35 (0-120) kW boiler, improved	NMVOC	44	g/GJ	1.3	g/kg
							g/kg
Small commercial or institutional boiler	11	UNECE TFEIP: sweden, briquette boilers 1.8-2 MW	TSP	36	g/GJ	1.1	g/kg
	11	UNECE TFEIP: sweden, briquette boilers 1.8-2 MW	THC	2	g/GJ	0.1	g/kg
	11	UNECE TFEIP: sweden, briquette boilers 1.8-2 MW	NOX	35	g/GJ	1.1	g/kg
	11	UNECE TFEIP: sweden, briquette boilers 1.8-2 MW	CO	270	g/GJ	8.3	g/kg
	29	BCC Research: industrial coke use	VOC	1.0 - 30	g/GJ	0.03-0.9	g/kg
	34	Rentz et al: coke, 200 (120-300) kW boiler, benchmark	NMVOC	30	g/GJ	0.9	g/kg
	34	Rentz et al: coke, 200 (120-300) kW boiler, improved	NMVOC	6	g/GJ	0.2	g/kg
Agricultural Heater		(none)					
CHP **a) steam turbine (ST)** **b) gas turbine (GT)** **c) comb. Cycle (CC)** **d) recipr. Engine (RE)** **e) condensing ST (CST)**		(none)					

Table B5: GAS EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire	30	EMEP default factors for gas use in fireplaces	SO2	0.5	g/GJ	0.00005	kg/therm
	30	EMEP default factors for gas use in fireplaces	NOX	50	g/GJ	0.0053	kg/therm
	30	EMEP default factors for gas use in fireplaces	PCDD/Fs	0.025	g/GJ	0.000003	kg/therm
	30	EMEP default factors for gas use in fireplaces	CO	20	g/GJ	0.0021	kg/therm
	30	EMEP default factors for gas use in fireplaces	NM VOC	6	g/GJ	0.0006	kg/therm
Domestic closed stove	19	IIASA: German figs for uncontrolled domestic gas "furnaces"	PM10	0.5	g/GJ	0.00005	kg/therm
	30	EMEP default factors for gas use in stoves	SO2	0.5	g/GJ	0.00005	kg/therm
	30	EMEP default factors for gas use in stoves	NOX	50	g/GJ	0.00528	kg/therm
	30	EMEP default factors for gas use in stoves	PCDD/Fs	2	ng/GJ		
	30	EMEP default factors for gas use in stoves	CO	10	g/GJ	0.0011	kg/therm
	30	EMEP default factors for gas use in stoves	NM VOC	3	g/GJ	0.0003	kg/therm
Domestic Boiler	11	UNECE TFEIP: dutch data for domestic gas use	VOC	6.3	g/GJ	0.0007	kg/therm
	11	UNECE TFEIP: dutch data for domestic gas use	SO2	0.22	g/GJ	0.00002	kg/therm
	11	UNECE TFEIP: dutch data for domestic gas use	NOX	57.5	g/GJ	0.0061	kg/therm
	11	UNECE TFEIP: dutch data for domestic gas use	CO	15.8	g/GJ	0.0017	kg/therm
	11	UNECE TFEIP: dutch data for domestic gas use	PM10	0.3	g/GJ	0.00003	kg/therm
	16	ERA research: Boiler Efs, natural gas	CO	8.5	g/GJ	0.0009	kg/therm
	16	ERA research: Boiler Efs, natural gas	NOX	40.2	g/GJ	0.0042	kg/therm
	16	ERA research: Boiler Efs, natural gas	PM10	4.8	g/GJ	0.0005	kg/therm
	16	ERA research: Boiler Efs, natural gas	SOX	0.2	g/GJ	0.00002	kg/therm
	16	ERA research: Boiler Efs, natural gas	VOC	2.1	g/GJ	0.0002	kg/therm
	30	EMEP default factors for gas use in domestic boilers	SO2	0.5	g/GJ	0.00005	kg/therm
	30	EMEP default factors for gas use in domestic boilers	NOX	70	g/GJ	0.0074	kg/therm
	30	EMEP default factors for gas use in domestic boilers	CO	units are a mess		30	ng/kj??
	30	EMEP default factors for gas use in domestic boilers	NM VOC	units are a mess		3	ng/kj??
Domestic Boiler	19	IIASA: German figs for uncontrolled domestic gas boilers	PM10	0.2	g/GJ	0.00002	kg/therm
				30		0.00317	
	29	BCC Research: UK use of gas in domestic appliances	VOC	5.0 - 30	g/GJ	0.0005-0.0032	kg/therm
	34	Rentz et al: gas, 35 (0-120) kW boiler, benchmark	NMVOC	15	g/GJ	0.00158	kg/therm
	34	Rentz et al: gas, 35 (0-120) kW boiler, improved	NMVOC	3	g/GJ	0.00032	kg/therm
	36	Russian POPs data: residential	BaP	1.5	mg/1000m3		
Small commercial or institutional boiler	7	Belarus: gas use in small & medium boilers	BaP	0.038	g/GJ	0.000004	kg/therm
	14	VCAPCD: gas fired combustion kit, 10-100 MMBTUh	benzene	0.0023	g/GJ	0.00000024	kg/therm
	14	VCAPCD: gas fired combustion kit, 10-100 MMBTUh	PAHs	0.0002	g/GJ	0.00000002	kg/therm
	18	MSC-E research: russian low capacity heat-power boilers	BaP	3.5	mg/tonne		
	18	MSC-E research: russian water boilers	BaP	1.8	mg/tonne		
	18	MSC-E research: russian heat-power boilers	BaP	1.5	mg/tonne		
	19	IIASA: German figs for uncontrolled industrial gas boilers	PM10	0.1	g/GJ	0.000011	kg/therm
	27	USEPA RWC research paper: conventional gas furnace	PAHs	0.00012	g/GJ	0.000000013	kg/therm
	27	USEPA RWC research paper: high efficiency gas furnace	PAHs	0.00003	g/GJ	0.000000003	kg/therm
	29	BCC Research: UK use of gas in commercial appliances	VOC	5	g/GJ	0.00053	kg/therm
	34	Rentz et al: gas, 200 (120-300) kW boiler, benchmark	NMVOC	5	g/GJ	0.00053	kg/therm
	34	Rentz et al: gas, 200 (120-300) kW boiler, improved	NMVOC	1	g/GJ	0.00011	kg/therm
	36	Russian POPs data: industry / public utility	BaP	1.5	mg/1000m3		
Agricultural Heater	11	UNECE TFEIP: dutch data for agricultural gas use	VOC	30	g/GJ	0.00317	kg/therm
	11	UNECE TFEIP: dutch data for agricultural gas use	SO2	0.22	g/GJ	0.00002	kg/therm
	11	UNECE TFEIP: dutch data for agricultural gas use	NOX	65	g/GJ	0.00686	kg/therm
	11	UNECE TFEIP: dutch data for agricultural gas use	CO	10	g/GJ	0.00106	kg/therm
	11	UNECE TFEIP: dutch data for agricultural gas use	PM10	0.15	g/GJ	0.00002	kg/therm
CHP	13	Aus power stations - avge for gas turbines	NOX	179	g/GJ	0.01888	kg/therm
a) steam turbine (ST)	13	Aus power stations - avge for gas turbines	CO	43	g/GJ	0.00454	kg/therm
b) gas turbine (GT)	13	Aus power stations - avge for gas turbines	NMVOC	2.1	g/GJ	0.00022	kg/therm

Table B6: LPG, Propane & Butane EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire		(none)					
Domestic closed stove	26	USEPA: fuel use in developing world home stoves, LPG	CO	14.9	g/kg	0.0318	kg/th
	26	USEPA: fuel use in developing world home stoves, LPG	TNMOC	18.8	g/kg	0.0402	kg/th
	26	USEPA: fuel use in developing world home stoves, LPG	TSP	0.51	g/kg	0.0011	kg/th
Domestic Boiler	11	UNECE TFEIP: dutch data on domestic LPG use	VOC	2	g/GJ	0.0002	kg/th
	11	UNECE TFEIP: dutch data on domestic LPG use	SO2	0.22	g/GJ	0.00002	kg/th
	11	UNECE TFEIP: dutch data on domestic LPG use	NOX	40	g/GJ	0.0042	kg/th
	11	UNECE TFEIP: dutch data on domestic LPG use	CO	10	g/GJ	0.0011	kg/th
	11	UNECE TFEIP: dutch data on domestic LPG use	PM10	2	g/GJ	0.0002	kg/th
Small commercial or institutional boiler	29	BCC Research: UK use of LPG in commercial appliances	VOC	5	g/GJ	0.0005	kg/th
Agricultural Heater	11	UNECE TFEIP: dutch data on agricultural LPG use	VOC	2	g/GJ	0.0002	kg/th
	11	UNECE TFEIP: dutch data on agricultural LPG use	SO2	0.22	g/GJ	0.00002	kg/th
	11	UNECE TFEIP: dutch data on agricultural LPG use	NOX	40	g/GJ	0.0042	kg/th
	11	UNECE TFEIP: dutch data on agricultural LPG use	CO	10	g/GJ	0.0011	kg/th
	11	UNECE TFEIP: dutch data on agricultural LPG use	PM10	2	g/GJ	0.0002	kg/th
CHP **a) steam turbine (ST)** **b) gas turbine (GT)** **c) comb. Cycle (CC)** **d) recipr. Engine (RE)** **e) condensing ST (CST)**		(none)					

Table B7: FUEL OIL EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire		(none)					
Domestic closed stove		(none)					
Domestic Boiler	29	BCC Research: UK use of residual oil in domestic appliances	VOC	10	g/GJ	0.4	g/kg
	33	Polish Efs for fuel oil use in residential sector	BaP	3.4	g/Mt		
	19	IIASA: German figs for uncontrolled domestic heavy fuel oil use	PM10	8.0-27	g/GJ	0.3-1.2	g/kg
	19	IIASA: EC figs for uncontrolled domestic heavy fuel oil use	PM10	50	g/GJ	2.2	g/kg
	19	RAINS figs for uncontrolled domestic heavy fuel oil use	PM10	20	g/GJ	0.9	g/kg
	36	Russian POPs data: residential	BaP	4.3	mg/t		
Small commercial or institutional boiler	16	ERA research: Boiler Efs, fuel oil #1, 5% sulfur	CO	15.6	g/GJ	0.7	g/kg
	16	ERA research: Boiler Efs, fuel oil #1, 5% sulfur	NOX	62.4	g/GJ	2.7	g/kg
	16	ERA research: Boiler Efs, fuel oil #1, 5% sulfur	PM10	3.1	g/GJ	0.1	g/kg
	16	ERA research: Boiler Efs, fuel oil #1, 5% sulfur	SOX	449	g/GJ	19.5	g/kg
	16	ERA research: Boiler Efs, fuel oil #1, 5% sulfur	VOC	0.6	g/GJ	0.03	g/kg
	16	ERA research: Boiler Efs, fuel oil #4, 5% sulfur	CO	15.4	g/GJ	0.7	g/kg
	16	ERA research: Boiler Efs, fuel oil #4, 5% sulfur	NOX	61.4	g/GJ	2.7	g/kg
	16	ERA research: Boiler Efs, fuel oil #4, 5% sulfur	PM10	18.5	g/GJ	0.8	g/kg
	16	ERA research: Boiler Efs, fuel oil #4, 5% sulfur	SOX	467	g/GJ	20.3	g/kg
	16	ERA research: Boiler Efs, fuel oil #4, 5% sulfur	VOC	0.6	g/GJ	0.03	g/kg
	16	ERA research: Boiler Efs, fuel oil #5, 5% sulfur	CO	15.4	g/GJ	0.7	g/kg
	16	ERA research: Boiler Efs, fuel oil #5, 5% sulfur	NOX	169	g/GJ	7.4	g/kg
	16	ERA research: Boiler Efs, fuel oil #5, 5% sulfur	PM10	26.4	g/GJ	1.1	g/kg
	16	ERA research: Boiler Efs, fuel oil #5, 5% sulfur	SOX	488	g/GJ	21.2	g/kg
	16	ERA research: Boiler Efs, fuel oil #5, 5% sulfur	VOC	0.9	g/GJ	0.04	g/kg
Small commercial or institutional boiler	18	MSC-E research: russian low capacity heat-power boilers	BaP	22	mg/tonne		
	18	MSC-E research: russian water boilers	BaP	13.2	mg/tonne		
	18	MSC-E research: russian heat-power boilers	BaP	4.3	mg/tonne		
	14	VCAPCD research: external combustion of #1-#2 fuel oil	benzene	0.014	g/GJ	0.0006	g/kg
	14	VCAPCD research: external combustion of #1-#2 fuel oil	toluene	0.014	g/GJ	0.0006	g/kg
	14	VCAPCD research: external combustion of #1-#2 fuel oil	PAHs	0.16	g/GJ	0.007	g/kg
	29	BCC Research: UK use of residual fuel oil in industry	VOC	8	g/GJ	0.35	g/kg
	19	IIASA: German figs for uncontrolled industrial heavy fuel oil use	PM10	3.0-14	g/GJ	0.1-0.6	g/kg
	19	IIASA: German figs for uncontrolled industrial boilers: heavy fuel oil	PM10	23	g/GJ	1.00	g/kg
	19	IIASA: EC figs for uncontrolled industrial boilers: heavy fuel oil	PM10	20	g/GJ	0.87	g/kg
	19	RAINS figs for uncontrolled industrial boilers: heavy fuel oil	PM10	15	g/GJ	0.65	g/kg
	36	Russian POPs data: industry / public utility	BaP	4.3	mg/t		
Agricultural Heater	33	Polish Efs for fuel oil use in agric sector	BaP	3.4	g/Mt		
CHP	13	Australian power station using fuel oil	NOX	186	g/GJ	8.09	g/kg
a) steam turbine (ST)	13	Australian power station using fuel oil	CO	14	g/GJ	0.61	g/kg
b) gas turbine (GT)	13	Australian power station using fuel oil	NMVOC	2.1	g/GJ	0.09	g/kg
c) comb. Cycle (CC)							
d) recipr. Engine (RE)	29	BCC Research: UK use of fuel oil in power plant	VOC	6.8	g/GJ	0.30	g/kg
e) condensing ST (CST)	34	Rentz et al: "oil", 200 (120-300) kW boiler, improv & abate	NMVOC	1	g/GJ	0.04	g/kg
	36	Russian POPs data: power plant	BaP	4.3	mg/t		

Table B8: BURNING OIL (KEROSENE) EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire		(none)					
Domestic closed stove	26	USEPA: fuel use in developing world home stoves, kerosene wick	CO	17.7	g/kg		
	26	USEPA: fuel use in developing world home stoves, kerosene wick	TNMOC	14.9	g/kg		
	26	USEPA: fuel use in developing world home stoves, kerosene wick	TSP	0.5	g/kg		
	26	USEPA: fuel use in developing world home stoves, kerosene pressure	CO	62.1	g/kg		
	26	USEPA: fuel use in developing world home stoves, kerosene pressure	TNMOC	19.2	g/kg		
	26	USEPA: fuel use in developing world home stoves, kerosene pressure	TSP	0.7	g/kg		
	19	IIASA: German figs for uncontrolled domestic light fuel oil use	PM10	1	g/GJ	0.05	g/kg
	19	IIASA: EC figs for uncontrolled domestic boiler:light fuel oil	PM10	30	g/GJ	1.39	g/kg
Domestic Boiler	11	UNECE TFEIP: dutch data on domestic "oil" use	VOC	15	g/GJ	0.69	g/kg
	11	UNECE TFEIP: dutch data on domestic "oil" use	SO2	87	g/GJ	4.02	g/kg
	11	UNECE TFEIP: dutch data on domestic "oil" use	NOX	50	g/GJ	2.31	g/kg
	11	UNECE TFEIP: dutch data on domestic "oil" use	CO	60	g/GJ	2.77	g/kg
	11	UNECE TFEIP: dutch data on domestic "oil" use	PM10	4.5	g/GJ	0.21	g/kg
	19	IIASA: German figs for uncontrolled domestic boiler:light fuel oil	PM10	0.2	g/GJ	0.01	g/kg
	19	RAINS figs for uncontrolled domestic boiler:light fuel oil	PM10	1	g/GJ	0.05	g/kg
	29	BCC Research: UK use of kerosene in domestic appliances	VOC	15	g/GJ	0.69	g/kg
	34	Rentz et al: "oil", 35 (0-120) kW boiler, benchmark	NMVOC	7.5	g/GJ	0.35	g/kg
	34	Rentz et al: "oil", 35 (0-120) kW boiler, improved	NMVOC	1.5	g/GJ	0.07	g/kg
	7	EMEP/CORINAIR default figs: small-scale oil combustion	PCDD/Fs	0.2	ugTEQ/t		
	7	EMEP/CORINAIR default figs: small-scale oil combustion	BaP	0.0043	g/t		
Small commercial or institutional boiler	34	Rentz et al: "oil", 200 (120-300) kW boiler, benchmark	NMVOC	5	g/GJ	0.23	g/kg
	34	Rentz et al: "oil", 200 (120-300) kW boiler, improved	NMVOC	1	g/GJ	0.05	g/kg
	19	IIASA: German figs for uncontrolled industrial boiler:light fuel oil	PM10	0.3	g/GJ	0.01	g/kg
	19	IIASA: EC figs for uncontrolled industrial boiler:light fuel oil	PM10	4	g/GJ	0.18	g/kg
	19	RAINS figs for uncontrolled industrial boiler:light fuel oil	PM10	1	g/GJ	0.05	g/kg
Agricultural Heater	11	UNECE TFEIP: dutch data on agricultural "oil" use	VOC	10	g/GJ	0.46	g/kg
	11	UNECE TFEIP: dutch data on agricultural "oil" use	SO2	0.22	g/GJ	0.01	g/kg
	11	UNECE TFEIP: dutch data on agricultural "oil" use	NOX	50	g/GJ	2.31	g/kg
	11	UNECE TFEIP: dutch data on agricultural "oil" use	CO	10	g/GJ	0.46	g/kg
	11	UNECE TFEIP: dutch data on agricultural "oil" use	PM10	4.5	g/GJ	0.21	g/kg
CHP							
a) steam turbine (ST)		(none)					
b) gas turbine (GT)							
c) comb. Cycle (CC)							
d) recipr. Engine (RE)							
e) condensing ST (CST)							

Table B9: BIOFUELS EF Info Summary

SECTOR	REF	Comments	Substance	EF	Units		
Domestic Open Fire	5	CPL Research: open fire, < 5kW, seasoned hardwood	PCDDs	0.068	gTEQ/MT		
	5	CPL Research: open fire, < 5kW, seasoned hardwood	PCDFs	0.16	gTEQ/MT		
	5	CPL Research: open fire, < 5kW, seasoned hardwood	PCBs	1.2	gTEF/MT		
	5	CPL Research: open fire, < 5kW, seasoned hardwood	PCNs	0.12	kg/MT		
	5	CPL Research: open fire, < 5kW, seasoned hardwood	33 PAHs	43	T/MT		
	5	CPL Research: open fire, < 5kW, seasoned hardwood	PM10	7.9	kT/MT		
	17	OMNI review: conventional stoves	16-PAH	0.223	g/kg		
	17	OMNI review:high-tech non-catalytic stoves	16-PAH	0.127	g/kg		
	17	OMNI review:catalytic stoves	16-PAH	0.161	g/kg		
	17	OMNI review: hundreds of source studies,	CO	64.1	g/dry kg		
	17	OMNI review: hundreds of source studies,	TPM	11.8	g/dry kg		
	9	Norway Inst of Tech: fireplaces	CO	6700	g/GJ	67	g/kg
	9	Norway Inst of Tech: fireplaces	VOC	520	g/GJ	5.2	g/kg
	9	Norway Inst of Tech: fireplaces	PAH	105	ug/MJ	1.1	g/T
	29	BCC Research: UK use of wood in domestic appliances	VOC	90-800	g/GJ	0.9-8.0	g/kg
	19	IIASA: German figs for uncontrolled domestic wood fireplaces	PM10	150	g/GJ	1.5	g/kg
Domestic closed stove	26	USEPA: biogas use in developing world home stoves	CO	1.95	g/kg		
	26	USEPA: biogas use in developing world home stoves	TNMOC	0.57	g/kg		
	26	USEPA: biogas use in developing world home stoves	TSP	0.53	g/kg		
	33	Polish Efs for wood use in residential sector	BaP	2.5	g/kT		
	19	IIASA: German figs for uncontrolled domestic wood stoves	PM10	150	g/GJ	1.5	g/kg
	19	IIASA: dutch figs for uncontrolled domestic wood "heating"	PM10	100-200	g/GJ	1.0-2.0	g/kg
	19	RAINS figs for domestic wood "heating"	PM10	150-290	g/GJ	1.5-2.9	g/kg
Domestic closed stove	7	EMEP/CORINAIR default figs: small-scale wood "furnaces"	PCDD/Fs	5	ugTEQ/t		
	7	EMEP/CORINAIR default figs: small-scale wood "furnaces"	BaP	5	g/t		
	27	USEPA: wood stove research, 1998, conventional stove	PAHs	40	g/GJ	0.4	g/kg
	27	USEPA: wood stove research, 1998, improved stove	PAHs	28	g/GJ	0.28	g/kg
	27	USEPA: wood stove research, 1998, test furnace A	PAHs	15.6	g/GJ	0.156	g/kg
	27	USEPA: wood stove research, 1998, test furnace B	PAHs	16.1	g/GJ	0.161	g/kg
	9	Norway Inst of Tech: traditional wood stoves	NOX	29	g/GJ	0.29	g/kg
	9	Norway Inst of Tech: traditional wood stoves	CO	7000	g/GJ	70	g/kg
	9	Norway Inst of Tech: traditional wood stoves	UHC as CH4	1750	g/GJ	17.5	g/kg
	9	Norway Inst of Tech: traditional wood stoves	VOC	670	g/GJ	6.7	g/kg
	9	Norway Inst of Tech: traditional wood stoves	PAH	3500	ug/MJ	35	g/T
	9	Norway Inst of Tech: modern wood stoves	NOX	58	g/GJ	0.58	g/kg
	9	Norway Inst of Tech: modern wood stoves	CO	1700	g/GJ	17	g/kg
	9	Norway Inst of Tech: modern wood stoves	UHC as CH4	200	g/GJ	2	g/kg
	9	Norway Inst of Tech: modern wood stoves	PAH	26	ug/MJ	0.26	g/T
	36	Russian POPs data: residential	BaP	2	g/t		
Domestic Boiler	11	UNECE TFEIP: Sweden, wood chip boilers 1.8-2 MW	TSP	51	g/GJ	0.51	g/kg
	11	UNECE TFEIP: Sweden, wood chip boilers 1.8-2 MW	THC	48	g/GJ	0.48	g/kg
	11	UNECE TFEIP: Sweden, wood chip boilers 1.8-2 MW	NOX	25	g/GJ	0.25	g/kg
	11	UNECE TFEIP: Sweden, wood chip boilers 1.8-2 MW	CO	3900	g/GJ	39	g/kg
	34	Rentz et al: wood, charcoal, 35 (0-120) kW boiler, benchmark	NMVOC	480	g/GJ	4.8	g/kg
	34	Rentz et al: wood, charcoal, 35 (0-120) kW boiler, improved	NMVOC	96	g/GJ	0.96	g/kg
	19	IIASA: German figs for uncontrolled domestic wood boilers	PM10	50	g/GJ	0.5	g/kg
	7	EMEP/CORINAIR default figs: small-scale wood combustion	PCDD/Fs	1.0-5	ugTEQ/t		
	7	EMEP/CORINAIR default figs: small-scale wood combustion	BaP	1.5-5	g/t		
Domestic Boiler	9	Norway Inst of Tech: wood boilers	NOX	101	g/GJ	1.01	g/kg
	9	Norway Inst of Tech: wood boilers	CO	5000	g/GJ	50	g/kg
	9	Norway Inst of Tech: wood boilers	UHC as CH4	1330	g/GJ	13.3	g/kg

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Appendix C

Summary of Emission Factors, sorted by Fuel and Sub-Sector

Table C1 – Summary of emission factors

FUEL	Sector	Species	EF	Units	Comment (country)		AP-42	Units	Comment	NAEI 2001	Units
Coal	Domestic	PM10	10 (9-11)	g/kg	open fire	(UK)				10.4	g/kg
(bituminous)		PM10	4 (3.4-4)	g/kg	stove	(D, ND)				10.4	g/kg
		PM10	4 (2.8-6)	g/kg	boiler	(D, UK)				10.4	g/kg
		VOC	14	g/kg	open fire	(UK)					
		VOC	0.6	g/kg	boiler	(UK)					
		CO	46-709	g/kg	stove	(UK)				45	g/kg
		CO	1.8	g/kg	boiler	(UK)				45	g/kg
		NOX	2.3	g/kg	stove	(ND)				1.42	g/kg
		NOX	6.2	g/kg	boiler	(UK)				1.42	g/kg
		SO2	13-104	g/kg	fuel-dependent	(ND, UK)					
Coal	Domestic	VOC	1.7	g/kg	boiler	(UK)					
(Anthracite)		NOX	8	g/kg	stove	(UK)				1.42	g/kg
Coal	CHP	PM10	1	g/kg	estimated from D data		1.1	g/kg	mean of several firing configs	2.4	g/kg
(bituminous)					on commercial boilers		6.6	g/kg	uncontrolled, spreader stoker		
							3.0	g/kg	uncontrolled overfeed stoker		
		VOC	0.03-0.1	g/kg		(UK, D)					
		CO	0.3	g/kg		(UK and AUS)	2.5	g/kg	spreader stoker, bit	4.1	g/kg
							0.25	g/kg	power station, pulv coal		
		NOX	8.0-10	g/kg		(UK, AUS)	5.0	g/kg	mean of several firing configs	4.7	g/kg
		SO2	50	g/kg	fuel-dependent	(UK)					
		BaP					1.9	10E-08g/kg			

FUEL	Sector	Species	EF	Units	Comment (country)		AP-42	Units	Comment	NAEI 2001	Units
Burning Oil	Domestic	PM10	0.05-1.4	g/kg	boiler	(D, EC)	0.1	g/kg		0.014	g/kg
		VOC	0.1-0.7	g/kg	boiler	(D, UK, ND)	0.4	g/kg			
		CO	2.8	g/kg	boiler	(ND)	0.7	g/kg		0.16	g/kg
		NOX	2.3	g/kg	boiler	(ND)	2.6	g/kg		2.21	g/kg
		SO2	4	g/kg	fuel dependent	(ND)	20.3	g/kg	based on 1% S fuel		
		NMVOC					0.1	g/kg			

Insufficient research regarding burning oil identified during this study, especially UK-based information.

Country abbreviations: **UK - United Kingdom, D - Germany, ND - Netherlands, USA - United States, NOR - Norway POL - Poland, RUS - Russia, AUS - Australia, EC - European Community**

FUEL	Sector	Species	EF	Units	Comment (country)		AP-42	Units	Comment	NAEI 2001	Units
LPG	Domestic	PM10	0.0002	kg/th	boiler	(ND)				0.00039	kg/th
		VOC	0.0002	kg/th	boiler	(ND, UK)					
		SO2	0.00002	kg/th	fuel-dependent	(ND)					
		NOX	0.0042	kg/th	boiler	(ND)				0.0049	kg/th
		CO	0.0011	kg/th	boiler	(ND)				0.00086	kg/th
LPG	P&C	PM10	0.0002	kg/th		(ND)	0.13	g/kg	total TPM	0.00029	kg/th
		VOC	0.0002-0.0005	kg/th		(ND)	0.13	g/kg			
		SO2	0.00002	kg/th	fuel-dependent	(ND)	0.02	g/kg			
		NOX	0.0042	kg/th		(ND)	4.4	g/kg		0.0094	kg/th
		CO	0.0011	kg/th		(ND)	0.66	g/kg		0.00025	kg/th

Insufficient research regarding LPG use identified during this study - most of this data from one source, the UNECE dutch data.

FUEL	Sector	Species	EF	Units	Comment (country)		AP-42	Units	Comment	NAEI 2001	Units
Fuel Oil	P&C	PM10	0.1-1.1	g/kg		(UK, D, EC)	1.08	g/kg		1.03	g/kg
		VOC	0.03-0.35	g/kg		(UK)	0.22	g/kg			
		NMVOC	nm				0.18	g/kg			
		BaP	4.0-22	g/KT		(RUS)					
		CO	0.7	g/kg		(UK)	0.67	g/kg	#5 fuel oil	0.5	g/kg
		NOX	2.7-7.4	g/kg		(UK)	7.42	g/kg	#5 fuel oil	7	g/kg
		SO2	20-21	g/kg	fuel-dependent	(UK)	21.2	g/kg	based on 1%S fuel		
Fuel Oil	Agric	PM10	0.1-1.1	g/kg	est., P&C	(UK, D, EC)				1.03	g/kg
		VOC	0.03-0.35	g/kg	est., P&C	(UK)					
		BaP	3.40	g/KT		(POL)					
		CO	0.7	g/kg	est., P&C	(UK)				0.5	g/kg
		NOX	2.7-7.4	g/kg	est., P&C	(UK)				7	g/kg
		SO2	20-21	g/kg	fuel-dependent	(UK)					
Fuel Oil	CHP	PM10	0.1-0.6	g/kg	est., P&C	(UK, D, EC)	0.9	g/kg	uncontrolled boiler	1.03	g/kg
		VOC	0.04-0.30	g/kg		(D, AUS, UK)	0.1	g/kg			
		NMVOC	nm				0.1	g/kg			
		BaP	0.6-3	g/KT	est., P&C	(RUS, USA)					
		CO	0.6	g/kg		(AUS)	0.7	g/kg		0.5	g/kg
		NOX	8.1	g/kg		(AUS)	6.3	g/kg		7.54	g/kg
		SO2	nm		fuel-dependent		21.2	g/kg	based on 1%S fuel		

FUEL	Sector	Species	EF	Units	Comment (country)		AP-42	Units	Comment	NAEI 2001	Units
Gas	Domestic	PM10	0.00005	kg/th	stove	(D)				0.000326	kg/th
		PM10	0.00002-0.0005	kg/th	boiler	(D, ND, UK)				0.000326	kg/th
		VOC	0.0006	kg/th	fire	(EC)					
		VOC	0.0003	kg/th	stove	(EC)					
		VOC	0.0002-0.0032	kg/th	boiler	(UK, ND, D)	0.021	kg/th			
		CO	0.0021	kg/th	fire	(EC)				0.00086	kg/th
		CO	0.0011	kg/th	stove	(EC)	0.15	kg/th		0.00086	kg/th
		CO	0.0009-0.0017	kg/th	boiler	(UK, ND)				0.00086	kg/th
		NOX	0.0053	kg/th	fire & stove	(EC)	0.36	kg/th		0.0049	kg/th
		NOX	0.0042-0.0061	kg/th	boiler	(UK, ND)				0.0049	kg/th
		SO2	0.00005	kg/th	fire & stove	(EC)	0.0023	kg/th			
		SO2	0.00002	kg/th	boiler	(UK, ND)					
Gas	P&C	PM10	0.00001	kg/th		(D)				0.000326	kg/th
		VOC	0.0001-0.0005	kg/th		(D, UK)	0.021	kg/th			
		BaP	0.003-0.008	10E-06 kg/th		(RUS)	0.0046	10E-06 kg/th	all sizes of unit		
		PAH	3.0-20	ug/th		(USA)					
		CO					0.32	kg/th	uncontrolled	0.00025	kg/th
		NOX					0.38	kg/th	uncontrolled	0.0049	kg/th
		SO2									
Gas	Agric	PM10	0.00002	kg/th		(ND)				0.000326	kg/th
		VOC	0.0032	kg/th		(ND)					
		BaP									
		PAH									
		CO	0.0011	kg/th		(ND)				0.00025	kg/th
		NOX	0.0069	kg/th		(ND)				0.0049	kg/th
		SO2	0.00002	kg/th		(ND)					
Gas	CHP	PM10	< 0.00001	kg/th	estimated	(D, ND)				0.000326	kg/th
		VOC	0.00005-0.002	kg/th		(UK, AUS, D)	0.021	kg/th			
		BaP									
		PAH									
		CO	0.002-0.013	kg/th		(UK, AUS)	0.32	kg/th		0.00025	kg/th
		NOX	0.004-0.02	kg/th		(UK, AUS)	0.53	kg/th	low-NOX	0.0095	kg/th
		SO2					0.002	kg/th			

FUEL	Sector	Species	EF	Units	Comment (country)		AP-42	Units	Comment	NAEI 2001	Units
Wood	Domestic	PM10	1.5-7.9	g/kg	open fire	(D, UK)	17.3	g/kg		7.9	g/kg
		PM10	1.0-2.9	g/kg	closed stove	(D, ND, EC)				7.9	g/kg
		PM10	0.5	g/kg	boiler	(D)				7.9	g/kg
		VOC	0.9-8.0	g/kg	open fire	(UK, NOR)	114.5	g/kg			
		VOC	2-17.5	g/kg	closed stove	(NOR)					
		VOC	1.0-13.3	g/kg	boiler	(D, NOR)					
		BaP	2.0-5	g/T	closed stove	(RUS, EC)	2	g/T		1.3	g/T
		BaP	1.5-5	g/T	boiler	(EC)				1.3	g/T
		PAH	0.1-1.1	g/kg	open fire	(USA, NOR)					
		PAH	0.16-0.4	g/kg	closed stove	(USA, NOR)					
		PAH	0.3	g/kg	boiler	(NOR)					
		CO	64-67	g/kg	open fire	(USA, NOR)	126.3	g/kg		99	g/kg
		CO	17-70	g/kg	closed stove	(NOR)				99	g/kg
		CO	50	g/kg	boiler	(NOR)				99	g/kg
		NOX					1.3	g/kg	fireplace		
		NOX	0.3-0.6	g/kg	closed stove	(NOR)				0.72	g/kg
		NOX	1	g/kg	boiler	(NOR)				0.72	g/kg
		SO2	0.03	g/kg	boiler, fuel dependent	(UK)					
		SO3					0.2	g/kg	fireplace		
		PCDD/F	0.23	gTEQ/MT	open fire	(UK)				0.24	gTEQ/MT