A REPORT BY ENVIROS CONSULTING LIMITED: MARCH 2006

DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS
EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES
## EXECUTIVE SUMMARY

### 1. INTRODUCTION
   1.1 Dioxins and dioxin-like polychlorinated biphenyls 3
   1.2 Stockholm Convention 3
   1.3 This study 4
   1.4 What are dioxins and PCBs? 5
   1.5 This report 7
   1.6 Acknowledgement 7

### 2. DIOXINS AND DIOXIN-LIKE PCBs
   2.1 Why are we concerned about dioxins and PCBs? 8
   2.2 Measuring dioxins and furans 8
   2.3 Mechanisms for release of dioxins and furans 10
   2.4 Release pathways 11

### 3. METHODS
   3.1 Domestic combustion 13
   3.2 Household waste combustion and bonfires 14
   3.3 Educational campaigns 15

### 4. DOMESTIC SOLID FUEL COMBUSTION
   4.1 Description of activities 17
   4.2 Emissions data for household heating and cooking with biomass 19
   4.3 Key factors affecting emissions from household heating and cooking with biomass 21
   4.4 Emissions data for domestic heating and cooking with fossil fuels 22
   4.5 Key factors affecting emissions from domestic heating and cooking with fossil fuels 24

### 5. DOMESTIC WASTE BURNING AND BONFIRES
   5.1 Emissions data for bonfires and fireworks 26
   5.2 Key factors affecting emissions from bonfires 27
   5.3 Emissions data for domestic waste burning 28
   5.4 Key factors affecting emissions from waste burning 30

### 6. NATIONAL INVENTORY
   6.1 Activity data 33
   6.2 National inventory 33

### 7. PUBLIC ENGAGEMENT
   7.1 The problem 37
7.2 Potential public awareness strategies 38
7.3 Current Promotional Activity - Domestic Solid Fuel Combustion 38
7.4 Current Promotional Activity - Domestic Waste Burning and Bonfires 39
7.5 Communications Strategy 41
7.6 What do we need to communicate? 42
7.7 Aim of a communications campaign 43
7.8 Campaign Options 44

8. CONCLUSIONS AND RECOMMENDATIONS 46
8.1 Technical conclusions 46
8.2 Key sources of dioxins and dioxin-like PCBs 46
8.3 Public information campaigns 47
8.4 Public information campaigns – example advice 50
8.5 Recommendations 51

9. REFERENCES 53

FIGURES
Figure 1 Chemical structure of 2,3,7,8-tetrachloro dibenzo-para-dioxin
Figure 2 Chemical structure of 2,3,7,8-tetrachloro dibenzofuran
Figure 3 Chemical structure of a polychlorinated biphenyl (PCB 77)
Figure 4 Estimated annual UK emissions of dioxins and furans to air
Figure 5 Estimated annual UK emissions of dioxins and furans in solid residues

APPENDICES
1. METALS LEVELS IN TREATED WOOD WASTE 2
2. SUPPORTING INFORMATION ON SOLID FUEL USE IN THE UK RESIDENTIAL SECTOR 2

A2.1 Introduction 2
A2.2 Legislation affecting Solid Fuel Combustion in the Residential Sector 2
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2.3 Fuels</td>
<td>3</td>
</tr>
<tr>
<td>A2.4 Appliances</td>
<td>7</td>
</tr>
<tr>
<td>A2.5 Propensity for fuels to produce dioxins</td>
<td>10</td>
</tr>
<tr>
<td>A2.6 Discussion</td>
<td>20</td>
</tr>
<tr>
<td>A2.7 Recommendations for further research</td>
<td>20</td>
</tr>
</tbody>
</table>
EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES

EXECUTIVE SUMMARY

1. Dioxins and dioxin-like polychlorinated biphenyls (PCBs) are a group of chemicals with similar structures. They are produced in extremely small amounts as the by-products of combustion processes. We are concerned about them because of their toxicity and long lifetime in the environment.

2. Good progress has been made in recent years in reducing emissions of these substances, mainly from industrial sources. This study focuses on household sources of dioxins and dioxin-like PCBs – burning of solid fuels in the home; burning of household waste by members of the public; and bonfires.

3. The UK has signed the Stockholm Convention on Persistent Organic Pollutants. This treaty requires the UK to take measures to reduce emissions of persistent organic pollutants, including dioxins and dioxin-like PCBs. The draft UK Dioxins Strategy contains identified three key areas requiring further research:

   - To identify combustion conditions required to reduce emissions of dioxins and dioxin-like PCB emissions from domestic solid fuel combustion (coal or wood)
   - To review information on the uncontrolled burning of household and garden waste with a view to reducing emissions of dioxin and dioxin-like PCBs
   - To Identify how educational campaigns could be used to disseminate best practice for reducing dioxins and dioxin-like PCB emissions from domestic sources.

4. Defra commissioned a consortium led by Enviros Consulting Ltd with Gastec at CRE Ltd and the National Society for Clean Air and Environmental Protection to research these areas.

5. It was found that emissions of dioxins and dioxin-like PCBs from domestic combustion sources are affected both by the nature of the materials burnt, and by the way in which they are burnt. In general, poor combustion conditions are likely to give rise to increased emissions of dioxins and dioxin-like PCBs. These conditions can be caused by a lack of air in the combustion zone, or by burning unseasoned or wet materials.

6. The presence of metals – in particular, copper – in the materials being burnt can give rise to increased emissions of dioxins and dioxin-like PCBs. Other factors being equal, an increased level of chlorine in the materials being burnt is also likely to give rise to an increase in emissions of dioxins and dioxin-like PCBs.

7. Estimates were made of emissions of dioxins and dioxin-like PCBs to air and in the ash arising from the sources under consideration. Although subject to considerable uncertainty, the data indicated that emissions from burning household waste could be the main source of emissions, followed by domestic coal burning. Bonfires and wood burning in fireplaces and stoves are likely to be less significant, although bonfires could be an important source of dioxins and dioxin-like PCBs in residues left at the site of the fire.
8. Based on these conclusions, three possible public engagement campaigns were proposed. A range of budget options within these campaigns were suggested.

- Campaign 1: “Don’t burn household waste indoors or outdoors, and especially not waste containing plastics”
- Campaign 2: “For people who have coal fires, choose coal with a low chlorine content, and make sure the fire burns efficiently”
- Campaign 3: “Don’t burn waste on bonfires – in particular, avoid burning plastics”

9. A number of further research recommendations were made, aimed at improving our understanding of the factors affecting emissions from the sources under consideration. Finally, recommendations regarding potential future policy issues were made. Firstly, it was recommended that a watching brief is maintained on the use of pellet burning stoves, to see if action to regulate the quality of wood pellets is needed. Secondly, any steps taken to discourage disposal of household waste could result in an increase in waste burning, and this would need to be strongly discouraged. Thirdly, consideration should be given to limiting the chlorine content of solid fuels supplied to households.
1. INTRODUCTION

1.1 Dioxins and dioxin-like polychlorinated biphenyls

Dioxins and dioxin-like polychlorinated biphenyls (PCBs) are a group of chemicals with similar structures. They are produced in extremely small amounts as the by-products of combustion processes. Society is concerned about them because of their toxicity, and because they persist in the environment and may bioaccumulate in food and human tissues. They are considered to have similar mechanisms of toxicity and so are grouped together when considering potential risks even though they originate from different sources.

Good progress has been made in recent years in reducing emissions of these substances (particularly from incinerators, power stations, steelworks and other industrial sources), so that public exposure to dioxins and dioxin-like PCBs is now less than a third of what it was 10 years ago (Defra, 2002). This report focuses on three domestic combustion sources – burning of solid fuels in the home; burning of household waste by members of the public; and bonfires.

1.2 Stockholm Convention

The UK is a signatory to the Stockholm Convention on Persistent Organic Pollutants (POPs). This treaty and the definition of POPs include dioxins and dioxin-like PCBs. This requires parties to take measures to reduce emissions with a view to eliminating the unintentional production of Persistent Organic Pollutants (known as uPOPs). The main tool for this is the production of a National Dioxin Action Plan. The purpose of the Dioxin Action Plan is to set out the restrictions in place to control emissions and to outline future actions to reduce environmental and human exposure to dioxins and furans and dioxin-like PCBs.

The Stockholm Protocol requires signatories to control the unintentional production of polychlorinated dibenzo-p-dioxins and dibenzofurans, hexachlorobenzene, and polychlorinated biphenyls. This report focuses on polychlorinated dibenzo-p-dioxins and dibenzofurans, which are referred to as “dioxins and furans,” together with co-planar dioxin-like PCBs. All these substances can be produced as the unintentional by-products of combustion processes. Also, some PCBs were produced commercially. Because of the similarity of the unintentional production sources, environmental behaviour, and potential effects, these are often grouped together. In this report, they are referred to as “dioxins and dioxin-like PCBs.”

There is increasing recognition of the relative contribution of emissions from diffuse sources – that is, small-scale sources which are not specifically regulated and controlled by central or local government. However, there is a lack of information on what the main diffuse sources are and what can be done to reduce emissions from these sources. Furthermore, diffuse sources are difficult to quantify and current emission inventories give estimated emissions which have substantial associated uncertainty.

Defra has previously commissioned a number of reports in order to review current research and to identify knowledge gaps and therefore prioritise further work. Lancaster University (Sweetman and Jones, 2003) prepared a report to review aspects of the current state of knowledge on dioxins and to identify possible research needs in support of policy objectives. A cost curve study considered a number of diffuse sources and recommended further control measures and the likely costs and impacts on emissions these controls would have (Defra, 2003).
The reports highlighted the need to update and improve aspects of diffuse source inventories. Defra’s consultation document “Dioxins and dioxin-like PCBs in the UK environment” (Defra, 2002) stated that “we know that activities such as domestic burning e.g. of garden refuse, not previously identified as important sources of dioxins, may in fact contribute significantly to total national emissions.” The Strategy contained the following proposal:

“It is proposed that Defra investigates releases from this sector to produce more reliable emissions estimates for the National Air Emissions Inventory. This information will be used to focus future action which might, for example, include the production of guidance on domestic burning and an investigation into whether changes in construction and/or furnishing materials could cut emissions from accidental fires.”

The consultation response summary confirmed that consultees supported this proposal: “On diffuse sources the need for further quantification of releases to ensure the correct targeting of measures was raised. Some suggested that further controls on bonfires were needed or other action such as the exclusion of chlorine containing materials. Public education in this area was also considered important by some. The potential costs of measures, for example to local authorities, was also raised.”

Three key areas requiring further research are:

♦ The need to investigate the combustion conditions required to reduce dioxin and dioxin-like PCBs emissions from domestic combustion sources in particular use of solid fuels (coal or wood)

♦ The need to review information on uncontrolled burning of waste, in particular burning of household and garden waste (bonfires) with a view to reducing emissions of dioxin and dioxin-like PCBs

♦ The need for a study to identify how educational campaigns could be used to disseminate best practice on waste management, in particular to reduce dioxin and dioxin-like PCBs.

1.3 This study

In view of this, Defra commissioned a consortium led by Enviros Consulting Ltd to carry out a research project. The project team members and their respective areas of expertise are given in Section 1.6:

The overall study aims were to: (a) improve the current level of uncertainty in estimated emissions from diffuse combustion sources; and (b) to recommend an appropriate strategy for encouraging members of the public to reduce these emissions.

The focus of the study was on strategies to reduce emissions of dioxins and dioxin-like PCBs, rather than specifically considering exposure reduction. This reflects the objective of the Stockholm Convention, to reduce emissions with a view to eliminating the unintentional production of Persistent Organic Pollutants. Reductions in emissions will result in reductions in environmental and human exposure to dioxins and furans and dioxin-like PCBs, although the link between reductions in emissions and reductions in exposure of humans or the natural environment has not been investigated in detail as part of this project.
The project objectives were defined as follows:

- **Objective 1**: To recommend strategies for promoting the use of combustion conditions appropriate for the reduction of dioxin and dioxin-like PCB emissions from domestic combustion sources, in particular use of solid fuels (wood or coal)

- **Objective 2**: To review and make recommendations on strategies for reducing dioxin and dioxin-like PCB emissions from bonfires and uncontrolled burning of waste

- **Objective 3**: Identify how educational campaigns could be used to disseminate best practice on waste management, in particular to reduce dioxins and dioxin-like PCBs

Objectives 1 and 2 are similar in scope. These two objectives are aimed at addressing two of the key sources of dioxins and dioxin-like PCBs. These sources are characterised by being:

(a) Currently areas of uncertainty in the scale and nature of dioxin and dioxin-like PCB emissions

(b) Possibly significant contributors to national emissions of dioxins and dioxin-like PCBs

(c) Potentially amenable to control strategies to deliver a significant reduction in emissions, provided public engagement can be secured.

Objective 3 will determine how successfully the information gained from Objectives 1 and 2 can be implemented to deliver a genuine, significant, quantifiable and beneficial reduction in emissions of dioxins and dioxin-like PCBs.

### 1.4 What are dioxins and PCBs?

The term “dioxins” is shorthand for polychlorinated dibenzo-para-dioxins. The term refers to a family of chemicals which comprise two benzene rings linked by oxygen atoms, and with a number of chlorine atoms present on the benzene rings. There is a closely related group of chemicals known as dibenzofurans (or more simply “furans”) which have a very similar chemical structure. In this case, the links consist of one oxygen atom, and one simple chemical bond. The chemical structures of the dioxin and furan groups are shown in Figures 1 and 2.

**Figure 1**  Chemical structure of 2,3,7,8-tetrachloro dibenzo-para-dioxin

[Diagram of 2,3,7,8-tetrachloro dibenzo-para-dioxin]

Figure courtesy of National Library of Medicine
A carbon atom is located at each point where two or more lines meet. Other members of the dioxin and furan groups have chlorine atoms linked to other carbon atoms.

Polychlorinated biphenyls (PCBs) have a similar structure to dioxins and furans. They again contain two benzene rings with a number of chlorine atoms, but in this case, the rings are linked by a single chemical bond rather than by "bridges" formed with oxygen atoms. The chemical structure of an example member of the PCB group is illustrated in Figure 3.

PCBs have chlorine atoms attached to one or more of the carbon atoms. The term “dioxin-like PCBs" covers certain coplanar-substituted polychlorinated biphenyls. The term “dioxin-like" refers to the fact that, like dioxins, the normal position of the benzene rings of these chemicals is in the same flat plane. This is due to the relative positions of the chlorine atoms on the two benzene rings. This means that these compounds have similar physical-chemical properties to dioxins and furans and result in a similar range of toxic responses. This study focuses on dioxin-like PCBs, and does not consider the much larger group of PCBs in general.

Because they are hydrophobic and resistant towards chemical conversion and absorption in the body, dioxins and dioxin-like PCBs persist and bioaccumulate in fatty tissues of animals and humans. Consequently, the principal route of chronic
population exposure is through the dietary consumption of animal fats, fish, shellfish, and dairy products.

1.5 This report

Chapter 2 of this report sets out the methods used to investigate the potential effects of the sources under consideration; to identify possible improvement measures; and to identify an appropriate public engagement strategy. Chapter 3 provides an introduction to the science of dioxin chemistry in combustion sources. Chapter 4 presents the study findings with regard to domestic solid fuel combustion. Chapter 5 presents the study findings with regard to domestic waste burning and bonfires. These findings are brought together in Chapter 6 to give an estimate of national emissions from the different source categories. In chapter 7, the issues relating to public engagement are presented. The study conclusions and recommendations are set out in Chapter A2.

1.6 Acknowledgement

The project team members and their respective areas of expertise are:

**Enviros Consulting Ltd:** Lead consultant and specialists in emissions from waste combustion and bonfires

**Gastec at CRE Ltd** Specialists in the field of domestic solid fuel combustion

**National Society for Clean Air** Specialists in public engagement

The contributions of the project team members, and the Defra Chemicals and GMO Policy Division are gratefully acknowledged. We are grateful for project funding by Defra.
2. DIOXINS AND DIOXIN-LIKE PCBBS

2.1 Why are we concerned about dioxins and PCBs?

Dioxins and furans and dioxin-like PCBs are produced as unwanted by-products of combustion. The United Nations Environment Programme describes dioxins and furans as follows (UNEP, 2005):

Dioxins – These chemicals are produced unintentionally due to incomplete combustion, as well as during the manufacture of certain pesticides and other chemicals. In addition, certain kinds of metal recycling and pulp and paper bleaching can release dioxins. Dioxins have also been found in automobile exhaust, tobacco smoke and wood and coal.

Furans – These compounds are produced unintentionally from the same processes that release dioxins, and they are also found in commercial mixtures of PCBs.

PCBs have been produced in relatively large quantities for industrial use. However, they are part of this project because they are emitted from the same combustion processes as dioxins and furans.

All the substances covered under the Stockholm Convention have the following characteristics:

- They are highly toxic to humans and animals;
- They are persistent, lasting for years or even decades before degrading into less dangerous forms;
- They evaporate and travel long distances through the air and through water; and
- They accumulate in fatty tissue.

Because of these serious concerns, the first aim of the Stockholm Protocol is to eliminate dangerous POPs, starting with the twelve worst. These twelve include dioxins and furans and dioxin-like PCBs.

2.2 Measuring dioxins and furans

Levels of a specific set of dioxins, furans and dioxin-like PCBs are normally recorded. Rather than reporting the levels of these individually, it is most common to report the levels of the individual chemicals multiplied by a factor to reflect the toxicity of each individual substance. This is referred to as a “toxic equivalent” or “toxic equivalency quotient” (TEQ) value. A number of different schemes have been proposed for the toxic equivalence factors, of which the most widespread are the NATO Committee on the Challenges of Modern Society (NATO-CCMS) values (dioxins and furans only) and the World Health Organisation values from 1998 (WHO98). The NATO-CCMS values are also referred to as International TEQ values (referred to as ITEQ). Data referred to as ITEQ in some instances includes dioxin-like PCBs based on an earlier WHO scheme from 1994, but more commonly refers to dioxins and furans alone. The WHO98 scheme includes updated toxic equivalence values for PCBs unless otherwise specified. The toxic equivalence values are set out in Table 1.
<table>
<thead>
<tr>
<th></th>
<th>ITEQ</th>
<th>NATO-CCMS</th>
<th>WHO98</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dioxins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,3,7,8-TetraCDD</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1,2,3,7,8-PentaCDD</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HexaCDD</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HexaCDD</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HexaCDD</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HeptaCDD</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8,9-OctaCDD</td>
<td>0.001</td>
<td>0.001</td>
<td>0.0001</td>
</tr>
<tr>
<td><strong>Furans</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,3,7,8-TetraCDF</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8-PentaCDF</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HexaCDF</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HexaCDF</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>2,3,4,6,7,8-HexaCDF</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HexaCDF</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HeptaCDF</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>1,2,3,4,7,8,9-HeptaCDF</td>
<td>0.001</td>
<td>0.001</td>
<td>0.01</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8,9-OctaCDF</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>PCBs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3,3',4,4'-TetraCB (PCB 77)</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
<tr>
<td>3,4,4',5-TetraCB (PCB 81)</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
<tr>
<td>2,3,3',4,4'-PentaCB (PCB 105)</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
<tr>
<td>2,3,4,4',5-PentaCB (PCB 114)</td>
<td>-</td>
<td>-</td>
<td>0.0005</td>
</tr>
<tr>
<td>2',3,4,4',5-PentaCB (PCB 118)</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
<tr>
<td>2',3,4,4',5-PentaCB (PCB 123)</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
<tr>
<td>3,3',4,4',5-PentaCB (PCB 126)</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
</tr>
<tr>
<td>2,3,3',4,4',5-HexaCB (PCB 156)</td>
<td>-</td>
<td>-</td>
<td>0.0005</td>
</tr>
<tr>
<td>2,3,3',4,4',5'-HexaCB (PCB 157)</td>
<td>-</td>
<td>-</td>
<td>0.0005</td>
</tr>
<tr>
<td>2',3,4,4',5,5'-HexaCB (PCB 167)</td>
<td>-</td>
<td>-</td>
<td>0.00001</td>
</tr>
<tr>
<td>3,3',4,4',5,5'-HexaCB (PCB 169)</td>
<td>-</td>
<td>-</td>
<td>0.01</td>
</tr>
<tr>
<td>2,3,3',4,4',5,5'-HeptaCB (PCB 189)</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

In this study, the toxic equivalence scheme used in the supporting research was transcribed and reported. If the scheme was not specified, then less weight was given to the reported data. Data estimates and recommendations are given in terms of the ITEQ scheme.
While there are differences between the toxic equivalence schemes, the similarity of the schemes means that differences between the schemes are likely to be less significant than the variability in the available scientific data from which emissions estimates can be built up. Differences between schemes are therefore considered unlikely to materially affect the emissions estimates given in this report.

Measurement of dioxins and furans is a highly challenging procedure, requiring detailed attention to the handling and analysis of samples. Methods and procedures have improved the consistency of measurements in recent years, but there remains a significant uncertainty of the order of ±25%, even when standard sampling and analysis protocols are followed.

2.3 Mechanisms for release of dioxins and furans

Dioxins and dioxin-like PCBs are formed as unintentional by-products in certain processes and activities. As well as being formed as unintentional by-products of manufacturing or disposal processes, dioxins and dioxin-like PCBs can also be present as contaminants in raw materials. This means that dioxins and dioxin-like PCBs can be released into the environment even in situations where dioxins and dioxin-like PCBs are not being formed.

Dioxins and dioxin-like PCBs are formed in two main kinds of processes: thermal processes, and chemical processes. The domestic sources under consideration in this project are combustion (i.e. thermal) processes, and there are two mechanisms at work which may result in dioxin and furan emissions.

(a) Dioxins and dioxin-like PCBs can be formed from the chemical elements (chlorine, carbon and oxygen), or from the "building blocks" (for example, chlorinated aromatic chemicals, or vinyl chloride present in polyvinyl chloride, PVC). The precursors needed for dioxin and dioxin-like PCBs to be formed are carbon and chlorine, in the presence of a limited amount of oxygen. This process can be more efficient if the chemicals are already present in a form which is close to that found in dioxins and dioxin-like PCBs. For example, organic chlorine may be more readily converted to dioxins and dioxin-like PCBs than inorganic chlorine. Aromatic chemicals (that is, organic chemicals containing benzene rings) are more readily converted to dioxins and dioxin-like PCBs than aliphatic substances (that is, organic chemicals which do not contain benzene rings).

The following aspects of a combustion process are important factors in determining the potential for formation of dioxin and dioxin-like PCBs:

- The temperature of the process must be in the region of 200-450 °C for dioxin formation to occur;
- Organic carbon needs to be present for formation of dioxins and dioxin-like PCBs to occur;
- Chlorine needs to be present for formation of dioxins and dioxin-like PCBs to occur;
- The formation of dioxins and furans can be enhanced by the presence of particles which have a high surface area – for example, ash or soot;
- If metals such as copper or cadmium are present in the combustion process, this can catalyse the formation of dioxins and dioxin-like PCBs;
Conversely, if sulphur is present, this can reduce the formation of dioxins and dioxin-like PCBs.

(b) If dioxins and furans are present in the materials being burned, these may be destroyed if the combustion takes place at sufficient temperature for a sufficient time. If dioxins are not destroyed, they will end up being released to the air during the combustion process, or will be retained in the ash residues.

This means that dioxins and dioxin-like PCBs are likely to be formed when metal-containing ashes are held at moderate temperatures between 200°C and 350°C in contact with incompletely combusted organic matter such as soot. Smouldering bonfires or ashes from domestic solid fuel combustions may provide such conditions.

The potential for domestic combustion processes to generate dioxins and dioxin-like PCBs depends on a combination of parameters, which are investigated in the following sections. However, in general terms, the formation of dioxins and dioxin-like PCBs is increased by:

- Poor combustion conditions, characterised by low oxygen levels, low flame temperatures (e.g. smouldering rather than full combustion), poor mixing of fuel and oxygen.

- An increased level of moisture in the fuel;

- An increased chlorine content of the fuel;

- The presence of metals and absence of sulphur in the fuel;

PAHs and dioxins/dioxin-like PCBs are both products of incomplete combustion. They are formed when combustion is poor due to one or more of the following factors - all of which are likely to apply to the case of bonfires or open burning of waste:

- low flame temperatures;

- incomplete mixing of fuel and oxygen; and/or

- low residence times at high temperatures.

In the past, PCBs were manufactured for use in commercial products such as dielectrics, hydraulic fluids, plastics, and paints. This no longer takes place, now that we understand better the toxic properties of these substances. However, the commercial manufacture of PCBs has left relatively large amounts of these substances in the environment, mostly in old or disused electrical equipment, and in landfills.

### 2.4 Release pathways

Dioxins and dioxin-like PCBs created during domestic combustion of solid fuels, biomass or wastes may be released in a number of ways.

- Dioxins may be emitted to the air in the gas phase, or within solid smoke particles. Dioxins and dioxin-like PCBs released in this way may be inhaled directly, but most human exposure takes place via indirect pathways. The main route is via the food chain, following deposition of
dioxins and furans to land; absorption by plants and animals; and consumption of food products. While our exposure to dioxins and furans has been reducing for some time, the food chain remains the main exposure route. The routes of greatest concern are consumption of fatty meats such as beef and lamb; consumption of oily fish; consumption of milk; and exposure of infants in breast milk.

- Dioxins may be present in the residual ash following the combustion process. In a controlled combustion process such as a domestic fire or stove, this ash is most likely to be disposed of via the normal local authority waste collection and disposal route. Any dioxins and furans present in this ash can be expected to be controlled, with a limited potential for exposure of members of the public. In some limited cases, the ash may be used as a soil additive by the householder, which could provide a localised exposure pathway if edible produce is grown on the soil which has been treated in this way.

- Dioxins present in the residual ash following an uncontrolled combustion process are of greater potential concern. The ash is likely to be left in place, and could be blown into the air, or affect the local soil/surface water/groundwater environment. Children may return to the site of the bonfire to play. These routes could potentially provide an opportunity for dioxins and dioxin-like PCBs to enter the food chain.
3. METHODS

3.1 Domestic combustion

The objective of this task is “to recommend strategies for promoting the use of combustion conditions appropriate for the reduction of dioxin and dioxin-like PCB emissions from domestic combustion sources, in particular use of solid fuels (wood or coal).”

The reliable combustion of high volatile solid fuels with minimum pollution at the domestic scale is extremely difficult, and is a goal which has been sought for over 100 years.

The focus of this task was to identify and recommend practical steps to reduce UK dioxin emissions. It is important to ensure that these steps are compatible with Defra’s policy of increasing the use of biomass crops for heating. For example the use of well seasoned wood offers the double advantage of increased thermal efficiency, together with a reduction in emissions of polycyclic aromatic hydrocarbons (PAHs). This may well be associated with reduced emissions of dioxins and dioxin-like PCBs. Conversely the replacement of existing log burners with pellet stoves, whilst potentially reducing emissions, would not necessarily be in line with Government policy to increase the use of biomass over the next few years.

Current knowledge on the contribution of domestic combustion to dioxin and PCB emissions was evaluated by drawing together information from a number of sources.

(a) A literature search using the British Library databases was carried out.

(b) Consultation was undertaken with specialists working in the area of combustion and atmospheric science, jointly with Objective 2. This focused on identifying any further information to be evaluated by the project team.

Leeds University Prof Alan Williams
Lancaster University Prof Ken Jones
SITA UK Ltd Dr Gev Eduljee

(c) Information available from the knowledge and expertise of the team was pooled. This included consideration of the chemical processes ongoing during domestic solid fuel combustion, and practical considerations relating to the design and operation of domestic combustion appliances. The possible influence of the chemical composition of materials being burnt; temperature; excess air, and fuel moisture levels were considered.

The literature and information covering the fundamental mechanisms for the formation and the estimated emissions dioxins and dioxin-like PCBs was reviewed.

These mechanisms were then mapped to the most likely formation scenarios within solid fuel domestic heating appliances. Based on this understanding, estimates of emissions from different appliance types and fuels were made. This considered the use of solid fuel for primary and secondary heating. By 2005, the vast majority of solid fuel appliances are now used for secondary or occasional heating, with primary heating usually being provided by gas, electricity or oil. A distinction was
made between controlled combustion (e.g. in a stove, range or fireplace) and uncontrolled combustion (e.g. bonfires and open burning of waste). From this, optimal combustion conditions for minimising dioxin emissions were identified. The practicalities of achieving these conditions in different environments were considered.

A strategy was then identified as to how these emissions can be minimised, aiming to identify approaches which are consistent with other Government objectives. Some of these (for example, the use of clean, well-seasoned wood) may offer win/win opportunities. Others (for example, avoiding domestic combustion of certain coals such as those with high volatile and/or chloride content) may impinge upon the rural poor, and could increase fuel poverty. These were highlighted, drawing attention to the potential disadvantages, and the potential reductions in emissions quantified where possible.

Other possibilities include a move to pellet stoves or other advanced combustion systems. While changes can be brought about in domestic fuel combustion (for example the Original Clean Air Act and the recent move to Condensing boilers), changes are likely to take place over a long period, and any new technology has to be robust and ready for widespread adoption.

### 3.2 Household waste combustion and bonfires

The objective of this task is "to review and make recommendations on strategies for reducing dioxin and dioxin-like PCB emissions from bonfires and uncontrolled burning of waste".

The consultation programme carried out by Defra highlighted the uncertainty associated with emissions of dioxins and furans from bonfires and uncontrolled burning of household waste. To some extent, this uncertainty is irreducible, because of the wide variety of materials which could potentially be burned, and the wide variety of conditions under which this combustion could take place. While placing a limit on the resolution of emissions estimates which is likely to be achievable, this variability provides the key to improving practice in this area. With such a wide variety of flammable materials accessible to members of the public, it is likely to be possible to provide guidance on those most likely to give rise to emissions of chlorinated semi-volatile organic compounds such as dioxins and dioxin-like PCBs. Similarly, basic guidance on "how to" and "how not to" construct a bonfire may prove effective in reducing emissions from these sources, if the evidence indicates that emissions of dioxins and dioxin-like PCBs are affected by the combustion conditions.

Current knowledge on the contribution of bonfires to dioxin and PCB emissions was evaluated by drawing together information from a number of sources.

(a) A literature search using the British Library databases was carried out.

(b) Consultation was undertaken with specialists working in the area of combustion and atmospheric science, as set out in Section 3.1.

(c) Information available from the knowledge and expertise of the team was pooled. This included consideration of the chemical processes ongoing during open combustion. The influence of the chemical composition of materials being burnt; temperature; access of air to the combustion zone; materials sizing; and the way the bonfire is constructed on emissions of dioxins and furans were considered.
Emissions factors for open burning of a range of materials are available under the United Kingdom National Atmospheric Emissions Inventory programme (www.naei.org.uk); from the United States Environmental Protection Agency (www.epa.gov/ttn/chief). Potentially useful emissions inventories are also compiled by the Dutch, Australian, Danish and Canadian environmental regulatory bodies. Guidance is provided by the European Environment Agency (EEA) on the compilation of emissions inventories for the purpose of reporting to the EPER database. These sources of data, together with any referenced research, were evaluated to identify any useful information on the factors influencing emissions of dioxins and furans.

The findings were summarised and the key principles affecting the emission of dioxins and dioxin-like PCBs will be evaluated to the extent supported by the available data.

3.3 Educational campaigns

The objective of this task is “to identify how educational campaigns could be used to disseminate best practice on waste management in particular to reduce dioxins and dioxin-like PCBs”

The information currently available and that produced from the first two tasks was reviewed. Candidate channels of communication were explored, which could be useful for raising awareness of the emissions and impacts from the burning of household waste and bonfires to the members of the general public carrying out these activities. The measures which are likely to be effective in providing education in good practice for waste disposal were considered.

The strategies for improving public awareness were evaluated from desk based research examining information currently available to the public on burning household waste, together with past and current campaigns aimed at public education, and changing behaviour which impacts on the local environment. The research encompassed an evaluation of the work which has been carried out at national, regional and local level, by organisations including Waste Watch, EnCams, NSCA, Defra and individual local authorities.

Potentially useful public education/communications strategies were identified, which would provide the most appropriate means of disseminating guidance and messages identified as appropriate under Objective 2. The recommendations covered options under the following categories:

**High Budget – high impact:** National TV/radio/press advertising campaign, supported by information leaflets, web-based resource

**Medium Budget - wide reach, lower impact:** Production of leaflets/guidance and national distribution to households (or target areas where waste burning is particularly prevalent). Development of guidance online – will need promotion to be really effective. Guidance and advertising could be focused at points where producers of household waste for burning are likely to see it – for example, DIY stores. Alternatively, the guidance could be aimed at schools, with the intention of increasing awareness in school children resulting in improved practices in the long term (30 years plus). This could support initiatives to adopt sustainability principles in all areas of the National Curriculum.
Lower Budget – uncertain reach/impact: Production of leaflets/guidance for distribution through local authorities – dependent on commitment of individual local authority environmental health/waste management services
4. DOMESTIC SOLID FUEL COMBUSTION

4.1 Description of activities

A discussion of current solid fuel combustion activities is given in Appendix 2.

4.1.1 Fuels

In summary, the main mineral fuel types used in the UK are bituminous coal, natural smokeless fuel (anthracite and dry steam coal), manufactured smokeless fuel (MSF) and manufactured non-smokeless fuel. Wood, manufactured logs (typically a wood/wax mix) and pellets are the principal biomass fuels.

The market for mineral fuels has consistently declined in the last fifty years from around 25 million tonnes per year to between 1 and 2 million tonnes per year. In contrast, the domestic wood market has increased in recent years, and is currently approximately 1 million tonnes per year.

Sales are not always of seasoned logs immediately fit for burning. Freshly felled timber can contain up to 60% moisture. It is important for efficient burning that logs are stored (seasoned) over winter. Seasoning reduces moisture contents to 20-25% and this can be reduced further to approximately 15%, by allowing the logs to dry in the house for a few weeks before burning.

At the special wood fuel end of the market the tonnage of wood chips and pellets sold for combustion is not likely to be more than a few thousand tonnes per year, but is likely to increase significantly in the next few years. Emissions from burning pellets are likely to be strongly dependent on the pellet quality rather than on combustion conditions. For example, pellets should be made from virgin wood rather than recycled materials such as pallets or demolition wood. If the market for pellet burning increases as expected, this may require regulation and enforcement to ensure that pellet quality is satisfactory.

4.1.2 Appliances

Solid fuel appliances can be conveniently broken into four broad categories:-

- Open fires
- Closed appliances
- Cookers
- Gravity fed boilers

Each of these categories is addressed with reference to their performance and current usage.

Open fires

Open fires with chimneys have been used in the UK for hundreds of years. They range from large inglenooks to the more conventional 18 inch-wide openings, which were a feature of almost all pre-1960 houses. Efficiencies of these appliances (defined as the proportion of supplied energy which is delivered as useful heat) are relatively low, achieving no more that 35% with smokeless fuel and 25% with...
bituminous coal for open fires without back boilers (water jackets). Inglenook fires have efficiencies as low as 15% when burning wood.

From about 1965, the efficiency of open fires was improved with high output boiler back (HOBB) units, to give hot water and central heating. HOBBs surround the fire bed with a water jacket and are designed to force the products of combustion through a restricted throat at the back of the appliance where heat is transferred to the water. Efficiency can then increase to 65%.

Open fires are estimated to account for around 13% of domestic solid fuel usage.

**Closed Appliances**

A closed appliance is ideal for heating a single room using solid fuel. The appliance may have a transparent or translucent window through which the fire can be observed. The appliance may also be fitted with a hot water boiler to provide central heating. Closed appliances are either designed to fit into a standard fireplace opening (in which case they are often known as roomheaters) or to be free-standing (in which case they are usually known as stoves).

Conventional roomheaters, originating from 1960s designs, normally burn larger anthracite lumps, MSF briquettes or coke. Free-standing stoves are normally designed to burn wood logs only or are multifuel appliances (often with different grate arrangements according to whether wood or mineral fuels are used).

Most closed appliances operate in an upburning mode, which can result in less efficient combustion and the generation of tars and smoke. Some closed appliances, however, burn in a downburning mode with consequential benefits of greater efficiency and the generation of less tar and smoke.

There is a small market in the UK for a range of boilers and stoves designed to burn only wood pellets and/or wood chips. This market is likely to grow significantly in the next decade.

Stoves and roomheaters are estimated to account for around 87% of domestic solid fuel usage.

**Cookers**

Range type cookers, which also often provide central heating, remain popular in country districts. Traditionally they were fired by solid fuel, but, for convenience – not least for control of cooking temperatures – oil and gas fired range cookers predominate present-day sales. The market for cookers is small.

Gas paths in cookers tend to be complex and they can become blocked by the smoke produced by bituminous coal unless cleaned regularly. Consequently, anthracite or MSF are normally the preferred fuel, although there are multi-fuel cooker designs which allow for the use of the complete range of solid fuels except petroleum coke.

**Gravity fed boilers**

The gravity fed boiler, fed by anthracite grains or beans, offers a high level of automation and cleanliness. They gained in popularity in the 70s and 80s but the numbers in use have declined in recent years, with current sales being very low.
4.2 Emissions data for household heating and cooking with biomass

4.2.1 Data review

There are normally no releases to water from waste combustion. Releases to land occur if the combustion process takes place directly on the ground, or if the residues are disposed of to land.

Measured emissions of dioxins and furans differ substantially even in repeat tests (e.g. CRE, 1995). Differences of a factor of four or more can occur between repeat tests, due to uncontrolled changes in combustion conditions.

Data from the UNEP toolkit (UNEP, 2003) derived from the European Dioxin Emissions Inventory (European Commission 2000 and supporting documents) are set out in the table below. These data are taken from studies carried out in a range of European countries, and may not be the most appropriate basis for estimating emissions from the UK mix of fuels and appliances.

<table>
<thead>
<tr>
<th>Release to air</th>
<th>Release in residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminated wood/biomass</td>
<td>1500 µg ITEQ/Terajoule energy available</td>
</tr>
<tr>
<td>Contaminated wood/biomass</td>
<td>26 µg ITEQ/tonne fuel</td>
</tr>
<tr>
<td>Contaminated wood/biomass</td>
<td>1.7 µg ITEQ/tonne fuel</td>
</tr>
<tr>
<td>Virgin wood/biomass</td>
<td>100 µg ITEQ/ Terajoule energy available</td>
</tr>
<tr>
<td>Virgin wood/biomass</td>
<td>2000 µg ITEQ/tonne residue</td>
</tr>
<tr>
<td>Virgin wood/biomass</td>
<td>20 µg ITEQ/tonne residue</td>
</tr>
</tbody>
</table>

Several studies have provided direct measurement of dioxins and furans in flue gas emissions from wood-burning stoves and fireplaces (Schatowitz et al., 1994; Vikelsoe et al., 1993; Bremmer et al., 1994; Bröker et al., 1992; Launhardt and Thoma, 2000; Environment Canada, 2001).

Emissions from burning beech wood sticks in stoves with open doors were found to be approximately 0.8 µg ITEQ/tonne of wood burned. With the doors closed, a moderate increase to 1.3 µg ITEQ/tonne of wood burned was observed.

Bremmer et al. (1994) reported results of testing performed with a cast-iron wood-burning stove with a combustion chamber lined with fire refractory clay. Measured emissions of dioxins and dioxin-like PCBs were in the range 1 to 3.3 µg ITEQ/tonne of wood burned (average 2.2 µg ITEQ/tonne), for low, moderate and high loads. Emissions from wood burning in a fireplace were found to be in the range 13 to 29 µg ITEQ/tonne (average 20 µg ITEQ/tonne).

Bröker et al. (1992) reported emissions from wood burning in a stove of 0.5 to 0.9 µg ITEQ/tonne. Emissions from fireplaces were in the range 0.2 to 1.1 µg ITEQ/tonne.

Environment Canada (2001) conducted a study on the release of dioxins and furans into the atmosphere by residential wood combustors. Emissions were found to be in the range 0.20 to 1.0 µg ITEQ/tonne wood burnt.
EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES

Quab and Fermann (1997) estimated that emissions from combustion of “slightly contaminated wood (excluding PCP)” are approximately 50 µg ITEQ/tonne, and from combustion of “PCP-contaminated wood,” approximately 500 µg ITEQ/tonne.

Results found by Tame et al (2003) indicate that the burning of untreated wood results in much lower emissions (0.05 ng ITEQ/kg) than of chromated copper arsenate (CCA) treated wood (78 ng ITEQ/kg) with the conclusion that the key step for formation of dioxins and dioxin-like PCBs is during the smouldering of the char (in Jones and Sweetman, 2004).

Similar conclusions are drawn by Lavric et al (2002) in their review. They conclude that the combustion of natural, uncontaminated wood leads to much lower dioxin and furan emissions than the combustion of contaminated wood. Emission levels taken from different sources ranged from 0.0025 to 0.73 ng ITEQ/Nm$^3$(11% O$_2$) for clean, natural wood and from 0.0022 to 18 ng ITEQ/Nm$^3$(11% O$_2$) for wood wastes.

Schatowitz et al (1994) found that seasoned beech wood sticks (0.8 – 1.3 µgTEQ$_{NATO}$ per tonne of wood burnt) wood chips (0.8 – 2.6 µgTEQ$_{NATO}$ per tonne of wood burnt) and uncoated chipboard chips (0.3 – 3.9 µgTEQ$_{NATO}$ per tonne of chipboard burnt) have significantly lower emissions than waste wood chips from the demolition of buildings (26 – 170 µgTEQ$_{NATO}$ per tonne of wood burnt).

Measured emissions of dioxins and dioxin-like PCBs from hardwood burning in a model fireplace were 0.21 µg ITEQ/tonne dioxins and furans, and 0.02 µg TEQ$_{WHO98}$/tonne dioxin-like PCBs (Lee et al, 2005). Alcock et al. (1999) estimated that national emissions of dioxins and furans from domestic burning of clean wood were in the range 2 to 18 g ITEQ per year (following Eduljee and Dyke, 1996), and from domestic burning of treated wood, 1 to 5 g ITEQ per year.

Gullett et al. (2003) found that burning oak logs in a woodstove gave rise to 0.25 µgTEQ dioxins and furans per tonne fuel burnt (average of 3 measurements). Burning oak, pine and artificial logs in a fireplace gave rise to 0.35 – 2.4 µgTEQ per tonne fuel burnt. PCBs were a minor constituent of the overall toxic equivalent load. Lavric et al. (2004) found that combustion of salt-laden wood gave rise to 17.1 µg ITEQ per tonne of wood burnt. Lavric et al. (2004) reported measurements of emissions of dioxins and furans from burning air-dried birch firewood in a Danish 5kW stove of 0.6 to 5.0 µg ITEQ per tonne of wood burnt.

Clement et al. (1985) found that levels of dioxins and furans in wood ash were higher in ash from open fires than in ash from stoves and fireplaces. Oehme and Muller studied dioxins and furans in ash from wood fired boilers, and found levels of 0.2 to 1.0 µg ITEQ per tonne ash. This corresponds to approximately 0.01 to 0.05 µg I TEQ per tonne wood burnt. A single waste wood burn was conducted, which gave rise to a level of 22 µg ITEQ dioxins and furans per tonne ash, corresponding to approximately 1.1 µgI TEQ per tonne wood burnt.

Lavric et al. (2004) reported 115 measurements of dioxin and furan levels in soot from five residential combustion sources, and found a range of 550 to 3500 µg ITEQ per tonne soot.

No information was found on emissions of dioxins and dioxin-like PCBs from pellet burning in domestic stoves, although these appliances are in general clean burning (Olsson, 2004). However, the stop/go nature of feeding pellet stoves/boilers could lead to higher that expected emissions of dioxins and dioxin-like PCBs. The low number of pellet burning stoves in the UK means that this is not at present a significant source of emissions to air, but the market for pellet stoves in the UK is expected to increase significantly in the next few years.
4.2.2 Emission factor ranges

For the purposes of this report, an emission factor is defined as the amount of dioxin and dioxin-like PCBs emitted from combustion of a fuel per mass of the fuel burnt.

The data did not support separate emissions factors for emissions from seasoned and unseasoned wood. The data which were specific to seasoned wood gave rise to a median emission factor similar to, but slightly higher than, the median emission factor based on the full data set. If anything, a lower value would be expected in practice. This indicates that any influence of seasoning of wood is less significant than other influences on emissions, and may be viewed as a limitation of the currently available data. Consequently, the recommended emission factor does not distinguish between seasoned and unseasoned wood.

The emissions factor ranges for domestic wood burning are:

- **Clean wood**
  - 0.043 - 11 µg ITEQ/tonne to air (5th – 95th percentile range of 11 values);
  - 0.01 – 0.6 µg ITEQ/tonne in residues (range of 3 values);

- **Contaminated wood**
  - 11 - 400 µg ITEQ/tonne to air (5th – 95th percentile range of 7 values);
  - 1 – 60 µg ITEQ/tonne in residues (range of 3 values)

Much of the data identified in this study was obtained from overseas studies, although research was largely based on recent combustion practices Europe and North America. There may be significant differences between UK practice and the conditions under which the research was carried out. However, in our view it is unlikely that combustion in appliances in the UK will differ sufficiently from overseas practice to give emissions lying outside the ranges of experimental data presented above.

4.3 Key factors affecting emissions from household heating and cooking with biomass

The UNEP toolkit (UNEP, 2003) indicates the significance of fuel quality, with substantial differences between emissions from burning virgin biomass compared to contaminated biomass such as treated or painted wood, or straw containing chlorinated pesticides. Typical chlorine contents of fuels are given in Table 7 (Appendix 2).

Environment Canada found that, in general, emissions were lower from newer stoves compared to older stoves. This is thought likely to be related to the improved burn-out reflecting a more homogeneous temperature regime within newer stoves.

Several studies have reported that combustion of treated or manufactured wood in stoves and fireplaces can result in significantly higher dioxin and dioxin-like PCB emission rates. A few researchers (e.g., Vikelsoe et al., 1993) have reported high emission rates when pentachlorophenol (PCP)-contaminated wood is combusted in residential wood stoves and furnaces.

In conclusion, the key issues affecting emissions from wood burning are firstly the use of seasoned versus unseasoned wood; and secondly, the use of treated versus untreated wood. Burning unseasoned wood can result in higher levels of dioxins
and furans in ash by a factor of approximately two (Schatowitz et al., 1993). Higher levels in emissions to air are also likely, although the data do not permit this to be quantified. This is because of the higher moisture content in unseasoned wood, which inhibits the combustion process and favours the formation of partially oxidised substances such as dioxins and PCBs.

Burning treated wood can result in higher emissions because some treatment products contain chlorine. Also, wood preservative treatments often contain metals, which can act as catalysts to the formation process of dioxins and PCBs.

It is recommended that combustion conditions should be optimised to give complete combustion, and to minimise smouldering conditions. This is normal common sense and good practice to achieve the most efficient use of fuel; however, as well as these benefits, the use of good combustion conditions also reduces dioxin and furan emissions.

Good combustion conditions may reduce emissions by a factor of two (Schatowitz et al., 1993) or more. If 20% of domestic wood fires are assumed to be carried out under inefficient conditions (e.g. due to the use of unseasoned wood or overnight banking) and these were changed to efficient conditions, then this is estimated to lead to a reduction of 0.03 – 2.5 g ITEQ dioxins and dioxin-like PCBs to air per year. Similarly, this is estimated to give rise to a reduction of 0.004 – 0.2 g ITEQ dioxins and dioxin-like PCBs in residues per year.

Waste wood has a chlorine content typically around ten times higher than clean wood (see Table 7). This indicates that a further control measure would be to avoid burning any waste wood in domestic fires and stoves. If this can be avoided, it could lead to a reduction of approximately 0.1 to 4 g ITEQ dioxins and dioxin-like PCBs to air per year, and a reduction of 0.01 to 0.6 g ITEQ dioxins and dioxin-like PCBs in residues per year.

4.4 Emissions data for domestic heating and cooking with fossil fuels

4.4.1 Data review

The following emission factors from coal combustion were derived by the UNEP from the European Dioxin Emissions Inventory (European Commission 2000 and supporting documents). These data are taken from studies carried out in a range of European countries:

- Emissions to air: 70 µgTEQ/Terajoule available heat, equivalent to approximately 2 µgTEQ /tonne fuel burned
- Emissions in residues: 5000 µg TEQ/tonne ash residue, equivalent to approximately 250 µgTEQ /tonne fuel burned, assuming weight of ash is 5% of weight of coal burned. This value is derived as a first estimate from a range of measurements taken from unspecified coal residues, and appears to be substantially out of line with two more specific values from CRE (1995) and the USEPA (1992) referred to below. This value was not used in the data evaluation.

Thuss et al. (1995) measured flue gas concentrations of dioxins and furans from a household heating system in Germany fired with either salt lignite coal (total chlorine content of 2,000 ppm) or normal lignite coal (total chlorine content of 300 ppm). Emissions were higher by a factor of 8 for the “salt” coal (2.7 µg TEQ_{NATO}/tonne) than for the “normal” coal (0.34 µg TEQ_{NATO}/tonne).
Eduljee and Dyke (1996) estimated that emissions of dioxins and furans from residential coal combustion units in the UK were 2.1 µg ITEQ/tonne for anthracite coal and 6 to 9 µg ITEQ/tonne for bituminous coal.

The USEPA carried out measurements on seven residential furnaces, and identified dioxin and dioxin-like PCB emissions of 60 µg ITEQ/tonne for anthracite coal, and 100 µg ITEQ/tonne for bituminous coal (USEPA, 1992 and following).

Emission factors to air for bituminous housecoal found by Lee et al. (2005) showed significantly higher emissions of persistent organic pollutants than for the burning of seasoned hardwood. The ratio of chlorine content in coal and in wood was 9:1. The ratio of dioxins in emissions from coal and wood was 4:1; the ratio of furans was 7:1; and the ratio of PCBs was 14:1. Measured emissions of dioxins and dioxin-like PCBs from bituminous coal burning in a model fireplace were 3.0 µg ITEQ/tonne dioxins and furans, and 0.2 µg TEQWHO98/tonne dioxin-like PCBs.

The draft USEPA review provided data on levels of dioxins and furans in solid wastes from coal combustion (USEPA, 2004). However, this was based on data from the utility industry. Measurements of dioxin and furan levels in 17 samples gave a dioxin and furan level of 0.6 µg ITEQ dioxins and furans per tonne ash, corresponding to approximately 0.03 µg ITEQ dioxins and furans per tonne fuel burnt.

Measurements carried out by CRE (1995) indicated that emissions to air and levels in ash of dioxins and furans from different fuel types were:

- Smokeless fuel: 2.1 µgTEQ per tonne fuel to air; 0.22 µgTEQ per tonne fuel in ash
- Anthracite: 4.7 µgTEQ per tonne fuel to air; 0.25 µgTEQ per tonne fuel in ash
- Bituminous coal: 5.7 µgTEQ per tonne fuel to air; 0.41 µgTEQ per tonne fuel in ash

### 4.4.2 Emission factor range

The emission factor ranges for domestic coal burning are:

- Smokeless coal/anthracite 2 - 50 µg ITEQ/tonne fuel to air (5th - 95th percentile range of 5 values); 0.03 – 0.2 µg ITEQ/tonne fuel in residues (range of 2 values);
- Bituminous coal 1.5 - 100 µg ITEQ/tonne fuel to air; 0.03 – 0.4 µg ITEQ/tonne fuel in residues (range of 2 values);

As for biomass combustion, much of the data identified in this study was obtained from overseas studies. Again, it is unlikely that combustion in appliances in the UK will differ sufficiently from overseas practice to give emissions lying outside the ranges of experimental data presented above.
4.5 Key factors affecting emissions from domestic heating and cooking with fossil fuels

The data produced by Thuss et al. (1995) indicates that emissions of dioxins and furans are strongly influenced by the presence of chlorine in the fuel. The data of Thuss et al indicated that, other factors being equal, emissions of dioxins and furans were approximately linearly related to the chlorine content of the fuel. It would be possible to derive an emission factor as a function of chlorine content from the information provided by Thuss et al., but this would be specific to the conditions used in these experiments.

A correlation between fuel chlorine content and emission of dioxins and furans is supported by Thomas and Spiro (1995). Although based on relatively old data, this paper indicated a general trend towards increased dioxin and furan emissions from sources with increased levels of chlorine in the fuel. Attention was also drawn to the significance of combustion conditions in determining emissions to air from combustion processes. It was found that the relatively high emissions of dioxins and dioxin-like PCBs at high chlorine content could be reduced significantly by the use of favourable operating conditions. Emissions from the burning of salt-laden wood from coastal areas were found to be 20 to 90 times higher than from 'normal wood' (Van Oostam and Ward, 1995 in Jones and Sweetman, 2004).

Besides the content of chlorine in the fuel a number of studies underline that low combustion temperatures and low oxygen levels are key conditions for the formation of dioxins and furans (cf. Lee et al. 2005, Hutzinger, Fiedler, 1988). Temperatures between 200-450°C with an optimum temperature at 350°C are most favourable for the formation of dioxins and furans. (e.g. Hay et al. 1986, Vogg et al. 1987 in Sweetman, Jones, 2004). Conversely, Lavric et al. (2004; Table 2) found that combustion conditions did not strongly influence emissions of dioxins and furans from coal burning.

Additionally an inadequate particulate removal and the presence of trace metals in the fuel acting as catalysts favour the formation of dioxins (Gullett 1998).

Eduljee and Dyke (1996) and USEPA (1997b) data indicated that bituminous coal results in higher emissions than anthracite. This may be due to the relative chlorine contents of the two fuels; the levels of trace metals and/or sulphur in the fuels; or the higher volatile content, and hence higher tar and smoke release from bituminous coals. Although the data set out in Table 14 do not indicate a systematic difference in the chlorine contents of anthracite and bituminous coals, such a difference does occur with UK coals so is considered to be a possible contributory factor.

The data in Table 14 indicate that the level of chlorine in coals ranges over two orders of magnitude from 0.01% to 1%. This indicates that the potential exists for reducing dioxin and dioxin-like PCB emissions from domestic combustion sources by reducing the chlorine content of fuels. This could be achieved by measures such as restricting sales of higher chlorine coals; public information and advice on the chlorine content of fuels; and/or tax incentives/subsidies for lower chlorine fuels.

If the average chlorine content of fuels used for domestic combustion could be reduced by half, this would reduce emissions of dioxins and dioxin-like PCBs to air by an estimated 0.7 – 34 g ITEQ per year. Similarly, dioxins and dioxin-like PCBs in solid residues would be reduced by an estimated 0.02 – 0.2 g ITEQ per year.

Any improvement in combustion conditions of domestic coal fires through design and/or usage would also be likely to reduce emissions of dioxins and furans. New
properties are generally more thermally efficient and require less heating than older properties. The efficiency of heating appliances is also generally improving. Together with restrictions on chimneys in new properties, this is likely to substantially reduce the use of solid fuels and consequently, reduce emissions of dioxins and dioxin-like PCBs from new properties.

Possible measures which could be promoted to improve the efficiency of domestic combustion processes are set out in Section 8.4.
5. **DOMESTIC WASTE BURNING AND BONFIRES**

5.1 **Emissions data for bonfires and fireworks**

5.1.1 **Data review**

The UNEP toolkit (UNEP, 2003) found that emissions to air from open burning of agricultural waste materials resulted in 0.5 \( \mu g \) ITEQ/tonne material burned for clean sources with good combustion conditions, and 30 \( \mu g \) ITEQ/tonne material burned under adverse conditions (i.e. smouldering flame; high humidity; wet ground; prior use of pesticides). Emissions to land were estimated to be 10 \( \mu g \) ITEQ/tonne material burned. These estimates were largely derived from sources considered separately in this review, including Bremmer et al. (2004); Schatowitz et al (1994), Ikeguchi and Tanaka (1999).

A study of Bonfire Night 1994 in Oxford by Dyke et al. (1997) found a fourfold increase of dioxin and furan levels in the ambient air over the course of the event. Levels in Cardiff were found to increase by a factor of 10, although this may have been influenced by a higher than usual number of bonfires in Cardiff. Likewise Lee, Green, Lohmann and Jones (1999) found increased concentrations in ambient air during the time of Bonfire Night. Lee et al. (1999) estimated that the uncontrolled burning of wood, garden refuse and wastes as well as the lighting of fireworks contribute approximately 30 g dioxins and furans TEQ\textsubscript{NATO}, equivalent to approximately 5-14\% of the estimated annual primary emissions in the UK. Farrar et al (2004) identified a doubling of airborne PCB levels in measurements taken during the Bonfire Night celebrations in 2000. More significant increases were identified for other persistent organic pollutants – in particular, PAHs (fourfold increase) and polybrominated diphenyl ethers (25 fold increase). It was estimated that approximately 5 kg of PCBs may be released to air during the Bonfire Night celebrations.

A study of PAH and dioxin emissions near two community bonfire sites in Northern Ireland showed significant increases in emissions on the lighting of the bonfires. The samples were taken in Belfast and Dunmurry. The concentrations of PAHs following the bonfire were observed to decrease whereas the concentration of dioxins continued to rise in one instance.

These studies reported an increase in emissions of dioxins and furans associated with bonfire and fireworks. These could have been due either to the bonfires, or to the fireworks, or to a combination of the two. Fleischer et al. (1999) conducted an experiment to measure the air emissions resulting specifically from seven types of firework. The paper cartridges and charges were separated from each firework and deflagrated separately in a steel chamber. Concentrations of dioxins and furans were measured both in air samples and in paper and ash samples. The results indicated that dioxins were not present in significant quantities in the air samples collected. This single study indicates that the increased emissions in the studies around bonfire and firework celebrations are likely to be due mainly to the bonfires rather than the fireworks, but variations between different firework types and manufacturers could give a different pattern at individual firework displays.

A study of dioxin/furan and PCB emissions in the food chain in areas potentially affected by animal pyres during the Foot and Mouth Disease (FMD) epidemic in 2001 found limited evidence for increased levels in eggs, poultry and lamb following the pyre (Rose et al., 2005). The FMD pyres were on a much larger scale than bonfires which would normally take place. Because the results associated with the
FMD pyres were marginal, it would be expected that bonfires would not normally give rise to detectable increases in levels of dioxins and furans and PCBs in the food chain.

Residential green waste burning may be a source of dioxins and furans. Gullet and Touati (2003) measured an average dioxin and furan emission factor of 20 µg TEQ WHO98/tonne during forest fire simulations, which may be representative of residential green waste burning.

The review carried out for Defra by Jones and Sweetman (2004) found that emissions of dioxins and furans are much greater when salt-laden wood is burned, than when wood with a low salt content is burned (results from coastal areas 20 or 90 times greater). Similarly, burning wood treated with chromated copper arsenate (CCA) resulted in much higher emissions than burning untreated wood (78 µg TEQ/tonne for treated wood, compared to 0.05 µg TEQ/tonne for untreated wood) (Tame et al 2003).

5.1.2 Emission factor ranges

There are very limited data on emissions from bonfires. The emission factor ranges from bonfires are:

Bonfires under good conditions 0.5 - 20 µg ITEQ/tonne to air (range of 2 values);
Bonfires under poor conditions 20 - 30 µg ITEQ/tonne to air (range of 2 values);
All bonfires: 10 µg ITEQ/tonne in residues (single value).

5.2 Key factors affecting emissions from bonfires

The data from the UNEP toolkit (UNEP, 2003) provide an indication that the use of clean fuel sources with good combustion conditions provided by a well ventilated fire result in relatively low dioxin and furan emissions. Conversely, the use of contaminated materials (e.g. wood coated with pesticides or preservatives), damp wood, wet ground and low levels of air resulting in smouldering results in relatively high dioxin and furan emissions.

Jones and Sweetman (2004) found that the key mechanism for dioxin and furan formation from wood burning is de-novo synthesis during the smouldering of the char. This in turn suggests that an effective method of reducing emissions from bonfires would be to reduce the time during which char is left to smoulder. Following the intense burning phase of a bonfire, quenching the char immediately rather than leaving the char to smoulder would reduce emissions of dioxins and furans from bonfires.

We have estimated that 50% of bonfires may be constructed poorly (e.g. with wet wood and little allowance for good air flow). If this proportion could be reduced to 25% with a public information campaign, this would result in an estimated reduction in emissions to air of dioxin and dioxin-like PCBs of 0.3 – 0.7 g ITEQ per year. It is not possible to estimate the benefit that this would confer in reduced emissions to land.

The rate of formation of dioxins is related to the amount of available chlorine in the materials being burnt. This means that, other factors being equal, bonfires made with materials with a high chlorine content would be expected to give rise to higher
emissions of dioxins and dioxin-like PCBs than bonfires with a lower chlorine content.

It is unreasonable to expect a significant change in the burning of woods with high chlorine contents, because materials burnt on bonfires are highly unlikely to have a known chlorine content (e.g. via labelling). It is possible that behaviours could be changed to reduce the amounts of chlorine-containing plastics burnt. However, further work would be useful to establish the benefit that this is likely to confer in terms of reduced emissions of dioxins and furans. The domestic products in which significant quantities of PVC may be present include:

<table>
<thead>
<tr>
<th>Window frames and doors</th>
<th>Interior vehicle trims and fabrics</th>
<th>Footballs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipework</td>
<td>Vehicle seat coatings</td>
<td>Swimming rings</td>
</tr>
<tr>
<td>Gutterings</td>
<td>Food packaging such as thermoformed cups</td>
<td>Garden hoses</td>
</tr>
<tr>
<td>Cables, ducting and conduits</td>
<td>Mineral water bottles</td>
<td>Folders and ring binders</td>
</tr>
<tr>
<td>Flooring</td>
<td>Cling films</td>
<td>Rulers</td>
</tr>
<tr>
<td>Computers</td>
<td>Non food packaging (e.g. cosmetics; detergent containers etc.)</td>
<td>Raincoats</td>
</tr>
<tr>
<td>Powertools</td>
<td>Bottle caps</td>
<td>Shoe soles</td>
</tr>
<tr>
<td>Electrical cords</td>
<td>Credit cards</td>
<td>Rubber boots</td>
</tr>
<tr>
<td>Phone systems, including mobile phones</td>
<td>Toys</td>
<td>Imitation leather</td>
</tr>
</tbody>
</table>

Guidance on avoiding combustion of these materials in bonfires could be helpful in reducing emissions of dioxins and furans from bonfires. The data in Table 14 indicate that about half of the chlorine in material burnt in bonfires could arise from PVC. This means that, if a campaign is successful in reducing the amount of PVC burnt on bonfires by 25%, this might be expected to reduce dioxin and dioxin-like PCB emissions to air from bonfires by approximately 0.2 – 0.4 g ITEQ per year. Emissions to land would be reduced by approximately 0.2 g ITEQ per year.

5.3 Emissions data for domestic waste burning

5.3.1 Data review

The UNEP toolkit defines uncontrolled domestic waste burning as including all instances where waste is burned with no pollution controls and therefore includes burning in the open in piles, in barrels or in home fires. For the reasons set out in Section 5.4, the emissions factors set out in this section are subject to considerable variability.
EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES

There are normally no releases to water from domestic waste combustion. Releases to land occur if the combustion process takes place directly on the ground, or the residues are disposed of to the land.

Studies of emissions from domestic backyard barrel burn of household waste were carried out by Gullett et al. (1999, 2000a, 2000b) and Lemieux et al. (2000) for the USEPA. This practice is much more widespread in the United States than in the UK – the USEPA estimates that approximately 18% of household waste in rural areas of the US is burnt in this way.

Lemieux (1997) measured emissions of dioxins and dioxin-like PCBs from barrel burning of unsorted waste from households in New York. The measured emission rate was 5.3 µg TEQ\text{WHO98}/tonne of waste burned. Ash samples were collected from these experiments and analyzed for dioxins and PCBs (although not dioxin-like PCBs). The level of dioxins and furans in ash from unsorted waste burning was 600 µg ITEQ/tonne ash, approximately equivalent to 2400 µg ITEQ/tonne waste burned. The level of dioxins and furans in ash from burning sorted waste was 2600 µg ITEQ/tonne ash, approximately equivalent to 10,000 µg ITEQ/tonne waste burned.

The subsequent tests showed a wide variation in the emissions of dioxins and furans (PCBs were not determined), with an average emission of 74 µg ITEQ/tonne of waste burned. The wide variation in emissions could not be explained by the controlled test parameters, and is likely to be due to factors such as the orientation of waste in the barrel.

The experiments included testing at three different PVC levels: 0, 1, and 7.5% by weight PVC, resulting in average emissions of 14, 200, and 4,900 µg ITEQ/tonne of waste burned, respectively. However, it is likely that increasing the amount of PVC in the waste being burned to a level of 7.5% affected the combustion characteristics significantly. The increase in emissions of dioxins and furans may therefore have been related to poorer combustion efficiency rather than an increase in the presence of chlorine. A re-evaluation of the USEPA work found a statistically significant link between the amount of chlorine in the feedstock and the amount of dioxin emissions, even at relatively low levels of PVC (Neurath, 2004). It is concluded that both combustion conditions and the amount of chlorine present are important influences on the evolution of dioxins and furans from waste burning. The relative significance of these aspects of the combustion process cannot be firmly established without further experiments under very carefully controlled conditions.

Wevers et al (2003) made measurements testing the open burning of garden and household waste. While both processes emitted dioxins and furans, the burning of household waste produced considerably higher amounts. (in Jones and Sweetman, 2004)

Schatowitz et al (1994) found that emissions from burning waste wood chips from building demolition waste were in the range 26 – 170 µg\text{TEQ}_{\text{NATO}} per tonne of wood burnt. Burning household waste consisting of two-thirds cardboard and one-third plastics produced 114 ng \text{TEQ}_{\text{NATO}}/m^3 of dioxins and furans in air emissions, corresponding to 3230 µg\text{TEQ}_{\text{NATO}}/tonne waste burnt. However, this result was a single measurement, and the quantity of PVC in the plastics was not determined.

Nakao et al. (2002) studied the ash from open burning of MSW at 16 sites following an earthquake in Japan in 1995. The average level of dioxins and dioxin-like PCBs in ash was found to be 540 µg\text{TEQ}/tonne ash dry weight. Oehme and Muller measured dioxins and furans in ash from combustion of a single sample of domestic...
waste in a 6 kW stove, and found levels of 353 pgTEQ per gram ash. This corresponds to approximately 100 µgTEQ per tonne of waste burnt.

The UNEP toolkit (UNEP, 2003) identified an emission factor of dioxins and dioxin-like PCBs to air of 300 µgTEQ/tonne material burned from uncontrolled domestic waste burning. The amount of dioxins and dioxin-like PCBs in solid residues was estimated to be 600 µgTEQ/tonne material burned. Open burning of construction/demolition wood waste was estimated to give rise to an emission to air of 60 µgTEQ/tonne material burned, and 10 µgTEQ/tonne material burned in solid residues. These estimates were largely derived from sources considered separately in this review.

Tyres are sometimes disposed of in open fires. The disposal of tyres is restricted under waste management legislation, and the National Atmospheric Emissions Inventory does not include tyres as a fuel source for bonfires. The relatively high sulphur content of tyres is likely to reduce the potential for formation of dioxins and furans. It is likely that the overall contribution of tyre burning to emissions of dioxins and dioxin-like PCBs is low.

Schatowitz et al. (1994) found that the combustion of household waste in a stove with the door closed resulted in dioxin and dioxin-like PCB emissions of 3,200 µg TEQ_NATO/tonne of waste burned.

Lavric et al. (2004) reported five measurements of dioxin and furan levels in soot from burning mixed wood, coal and waste, with a range of 1160 to 10700 µg ITEQ per tonne soot.

5.3.2 Emission factor ranges

The emissions factor ranges for domestic waste burning are:

- **Domestic waste burning (low PVC)**: 5.3 – 3200 µg ITEQ/tonne to air (range of four values);
- **Domestic waste burning (high PVC)**: 4900 µg ITEQ/tonne to air (single value – may be affected by compaction and orientation of waste);
- **Domestic waste burning**: 100 – 2400 µg ITEQ/tonne in residues (range of four values);

The wide range in values reflects the disparate make-up of domestic waste, and the potentially significant influence of the detailed arrangement of waste during combustion.

As for biomass combustion, much of the data identified in this study was obtained from overseas studies. Again, it is unlikely that combustion in appliances in the UK will differ sufficiently from overseas practice to give emissions lying outside the ranges of experimental data presented above.

5.4 Key factors affecting emissions from waste burning

Emissions to air from burning of domestic and similar wastes in uncontrolled conditions have been measured in the US from trials where domestic waste was combusted in a barrel (Lemieux 1997, Gullett et al. 1999, Lemieux et al. 2000). Emissions to air vary considerably depending on the conditions of combustion and
the composition of the waste. The range of measured emissions extends from under 9 µg TEQ\textsubscript{WHO98}/tonne of waste burned to over 6,000 µg TEQ\textsubscript{WHO98}/tonne of waste burned. Repeatability of data is generally poor, indicating that there will inevitably be a wide variability in emissions from individual fires.

Higher emissions were found when high levels of organic chlorine were burned. Polyvinyl chloride is a prevalent material in domestic waste, which, when burnt, can provide the building-blocks for formation of dioxins and dioxin-like PCBs. Burning waste containing PVC at levels of up to 7.5% in the waste resulted in emissions of 3,500 to 6,700 µg TEQ\textsubscript{WHO98}/tonne of waste burned. However, this increase is likely to be due to a combination of the increased chlorine content of the waste, together with other changes in combustion brought about by the presence of such a high PVC loading in the waste. The wide variability in results suggests that factors other than the chlorine content of the waste were likely to have been responsible for much of the increase in emissions of dioxins and furans. For example, waste orientation, oxygen levels and duration of burn-out may have played a role in giving rise to increased emissions of dioxins and furans with higher PVC levels in the waste.

The presence of high levels of copper in the waste can act as a catalyst to the formation of dioxins and furans. Burning wood with copper impregnation resulted in recorded emissions of 2,700 µg TEQ\textsubscript{WHO98}/tonne of waste burned.

Poor combustion conditions can also contribute to increased dioxin, furan and dioxin-like PCB emissions. Emissions of up to 1,000 µg TEQ\textsubscript{WHO98}/tonne were obtained by increasing the load, increasing the moisture content of the waste to be burned, compressing the waste before burning, and including wastes with a high inorganic chlorine content.

Lavric et al. (2004; Table 2) found that burning domestic waste under poor conditions could give rise to an increase in emissions of dioxins and furans by a factor of approximately 2 to 3, compared to good combustion conditions.

The materials being burnt also have a critical influence on emissions of dioxins and dioxin-like PCBs. This may be a direct result of the chemical content of the waste materials (e.g. metal, sulphur or chlorine content), or as an indirect result of the efficiency of combustion when different materials are burned. Ikeguchi and Tanaka reported emission factors for the open burning of various wastes (220 µg TEQ/tonne for scrap tyres; 1,000 µg TEQ/tonne for electric wire tube; and 6,600 µg TEQ/tonne for agricultural plastics (mainly PVC)).

It is relatively common to see fires used to dispose of wastes from construction and demolition – these are often predominantly burning treated wood but may also be used to dispose of other materials. Again little information is available either on the amounts burned or on emissions. The factors identified above which influence emissions from burning household waste are also likely to apply to the burning of construction/demolition waste: dioxin and dioxin-like PCB emissions are increased by the presence of organic chlorine; the presence of metals; high compaction; and high moisture levels.

The UNEP toolkit reported that amounts of dioxins and dioxin-like PCBs in solid residues depend on the conditions in the fire and the nature of the materials. The amount of dioxins and dioxin-like PCBs formed is likely to be increased if treated wood is burned; by the use of mixed fire loads; and poor combustion conditions.

A strategy to reduce emissions of dioxins and furans from domestic waste burning could therefore focus on three aspects:
Firstly, domestic waste should be disposed of via the proper routes provided by the local authority, and should not be burned in the open. This advice also covers indoor appliances, which should not be used to burn household waste, particularly now that good quality kerbside collection services are being offered by many local authorities. Eliminating the burning of domestic waste could result in a reduction in emissions of dioxins and dioxin-like PCBs to air of 1 gITEQ per year, with a similar reduction in emissions in residues. The upper end of these ranges represent a very significant potential reduction in emissions of dioxins and dioxin-like PCBs.

Secondly, burning under good combustion conditions would be preferable to burning under poor combustion conditions. However, we do not recommend pursuing a strategy based on this advice because of the risk of a mixed message regarding the undesirability of open burning of household waste.

Thirdly, burning of materials with high levels of copper or chlorine should be avoided. Waste materials containing high levels of chlorine are listed in Section 5.1.2. Around half of the chlorine in domestic waste may be due to the PVC content. If the amount of PVC burnt in domestic waste were reduced by 25%, this could result in a reduction in emissions to air of dioxins and dioxin-like PCBs of 0.4 – 47 µg ITEQ per year. The reduction in emissions of dioxins and dioxin-like PCBs in residues would be 1 – 35 µg ITEQ per year.
6. NATIONAL INVENTORY

6.1 Activity data

The estimated amounts of fuels burned in domestic properties are set out in Table 3.

<table>
<thead>
<tr>
<th>Activity/fuel type</th>
<th>Amount</th>
<th>Data quality</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic combustion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>1000000 T/year</td>
<td>Moderate</td>
<td>Appendix 2</td>
</tr>
<tr>
<td>Contaminated wood</td>
<td>10200 T/year</td>
<td>Not known</td>
<td>NAEI</td>
</tr>
<tr>
<td>Smokeless coal/anthracite</td>
<td>650000 T/year</td>
<td>Moderate</td>
<td>Appendix 2</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>450000 T/year</td>
<td>Moderate</td>
<td>Appendix 2</td>
</tr>
<tr>
<td>Bonfires</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material burnt</td>
<td>140600 T/year</td>
<td>Not known</td>
<td>NAEI</td>
</tr>
<tr>
<td>Proportion burnt under poor combustion conditions</td>
<td>50%</td>
<td>Poor</td>
<td>Estimate</td>
</tr>
<tr>
<td>Domestic waste burning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic waste burnt</td>
<td>121000 T/year</td>
<td>Not known</td>
<td>NAEI</td>
</tr>
<tr>
<td>Proportion of waste burnt which is plastic</td>
<td>6%</td>
<td>Not known</td>
<td>NAEI</td>
</tr>
</tbody>
</table>

Defra has a policy of increasing the use of biomass crops for domestic heating. This may result in an increase in the amount of wood used for domestic combustion in the future. The cost of waste disposal is also likely to rise in the future, as further alternatives to landfill are developed and implemented. This could result in an increase in the amount of domestic and commercial waste which is burnt, as a means to reduce disposal costs. There may also be a move towards spreading the ashes to land rather than disposal via the proper routes. A move to paying for household waste collection by mass or volume would be a particular risk, as there would be a clear financial incentive to reduce the amount of waste by combustion.

6.2 National inventory

Drawing together this information with that set out in Chapters 4 and 5 provides a provisional national inventory of dioxin and dioxin-like PCB emissions from domestic solid fuel and waste combustion. The national inventory was derived by multiplying the estimated annual fuel usage by the appropriate emission factor ranges from Chapters 4 and 5. This inventory will primarily be useful to support or cross-check the existing national dioxin and dioxin-like PCB emissions inventory (e.g. Adams, 2005), and does not replace the national inventory estimates.

The data ranges quoted in Table 3 are the 5th to 95th percentile ranges of published data values, for sources with five or more published data values. For those sources with less than five published values, the data ranges quoted are the minimum and maximum values. Emissions to air from domestic solid fuel combustion have five or more published values, so the data for these sources are based on the 5th to 95th percentile ranges. Emissions to air from bonfires, emissions to air from waste
burning, and emissions in solid residues from all sources have fewer than five published values, so the data for these sources are based on the minimum and maximum reported values.

Emissions are reported as ITEQ dioxins and furans. There is relatively little data available on emissions of dioxin-like PCBs to air or in solid residues. The available information indicates that dioxin-like PCBs are present in greater mass than dioxins and furans, but their relatively low toxicity means that they contribute a small proportion of the toxic burden of emissions.

**Table 4 Estimated inventory of dioxin and furan emissions from domestic combustion sources**

<table>
<thead>
<tr>
<th>Source</th>
<th>Estimated annual UK emission to air</th>
<th>Estimated annual UK emission in residues</th>
<th>Main route for disposal of solid residues</th>
<th>Data quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean wood</td>
<td>0.14 – 11</td>
<td>0.01 – 0.6</td>
<td>Waste disposal or use as soil improver</td>
<td>Good</td>
</tr>
<tr>
<td>Contaminated wood</td>
<td>0.12 – 4</td>
<td>0.01 – 0.6</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Smokeless coal/anthracite</td>
<td>1.0 – 32</td>
<td>0.02 – 0.15</td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>0.7 – 35</td>
<td>0.014 – 0.18</td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Bonfires Good conditions</td>
<td>0.04 – 1.4</td>
<td>1.4 (single value)</td>
<td>Left at site of bonfire</td>
<td>Poor</td>
</tr>
<tr>
<td>Bonfires Poor conditions</td>
<td>1.4 – 2.1</td>
<td></td>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>Domestic waste burning</td>
<td>0.6 – 584</td>
<td>12 – 290</td>
<td>Left at site of fire</td>
<td>Poor</td>
</tr>
<tr>
<td>Total</td>
<td>7 – 650</td>
<td>14 – 300</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The emissions estimates are shown graphically in Figure 4 and Figure 5.
The data in Table 4, Figure 4 and Figure 5 illustrate the variability in the source dataset, together with the low number of measurements particularly for bonfire emissions.

The most potentially significant source of emissions to air is domestic waste burning. Of the other sources, coal burning is potentially the next most significant. The range of estimates means that it is not possible to be definitive about the sources which make the most significant contribution to emissions to air.
Domestic waste burning is also likely to be the most significant source of emissions of dioxins and dioxin-like PCBs in residues. This is a particular concern because these residues are unlikely to be properly disposed of, and there may well be pathways for public exposure to dioxins and dioxin-like PCBs in these residues.

This source is also of concern because of the risk that combustion of domestic waste may increase in response to increasing cost of disposal. As noted above, if household waste collection is charged by mass or volume rather than as a component of Council tax, this could increase the incentive to burn waste in order to reduce the amount requiring collection and disposal.

At the same time, local authorities are offering increased opportunities for recycling and composting – for example, subsidised provision of composting bins, and kerbside collection of recyclables. This may result in a change in the nature of wastes burnt in the home. This could result in less combustible material being present in the waste as a result of separate collection of paper. Alternatively, it could result in less chlorine containing materials in the waste as a result of the separate collection of plastics. The potential effects of changes such as these on emissions of dioxins and furans cannot be evaluated at present, and is likely to depend on the nature and effectiveness of the schemes operating in different areas.

The emissions estimates in Table 4 are consistent with the national atmospheric emissions inventory estimates for 2003:

- Domestic coal and solid fuel: 3.3 grams TEQ dioxin and furan
- Domestic wood combustion: 0.22 grams TEQ dioxin and furan
- Bonfire Night: 6.8 grams TEQ dioxin and furan

Domestic waste burning does not appear in the National Atmospheric Emissions Inventory as a source of dioxins and furans, although the category "accidental fires" is estimated to result in 58 grams TEQ of dioxin and furan emissions per year.
7. PUBLIC ENGAGEMENT

7.1 The problem

The research described above has identified the main sources of emissions of dioxins and dioxin-like PCBs to the air and in residues (see Table 4).

The communications strategy will need to be driven by these outcomes, taking into account the main sources of emissions by output.

1. **Burning household waste in the open or on domestic appliances** is identified as the most significant source of emissions of dioxins and furans, whether burnt as part of a bonfire, or burnt as a domestic waste fire. Both the combustion conditions and the chlorine content of materials being burnt are important in determining the amount of dioxins and furans emitted from burning waste. The people most likely to be carrying out these activities represent a challenging target audience as it is not easily identified, and messages would need to focus on identifying the polluting material and alternative disposal. Materials made from or containing PVC are likely to be the largest component of chlorine in household waste. However, rather than focusing specifically on PVC or combustion conditions, a message that all burning of plastics or of household waste is unacceptable may be simpler to convey.

However, this issue is already being addressed in recycling campaigns – for example, much work is being undertaken at local and national level to encourage waste separation and recycling. This means that other initiatives encouraging the removal of this material from the waste stream may also address the issue of dioxin and furan emissions to an extent. Local authorities may be able to identify areas where this sort of burning is a particular problem.

2. In tandem with this, bonfires around the Bonfire Night celebration have been identified as being responsible for as much as 14% of emissions to air. This means that a campaign to promote ‘cleaner’ bonfires around bonfire night could make a significant contribution to reducing these emissions – promoting recycling and re-use of plastic. This would need to give a positive message rather than negative – that is, a cleaner bonfire would be more enjoyable (avoiding unpleasant acrid smoke leading to choking bonfire guests) as well as better for the environment.

3. Burning anthracite and bituminous coal is the next greatest source. These emissions may be amenable to control by using relatively low chlorine fuels, and by improving combustion conditions. It should be possible to achieve good results in this area by working with fuel and appliance suppliers and distributors and manufacturers to tackle this source. Identifying problem areas and targeting these should be cost effective.

4. Garden waste – while bonfires are a relatively minor contributor to emissions to air, they may be more significant in terms of emissions in residues. These residues are not normally controlled. There is also a public perception that they can be a problem (e.g. smoke nuisance). Here there is a specific target market with an existing communications infrastructure – organisations, press, TV, radio, gardening celebrities (e.g. Bob Flowerdew, Kim Wilde – Recycle Now, Monty Don), gardening press, which can relatively easily be tapped into, and may well reach the household waste burners as well if DIY stores and garden centres are used for promotion.
5. Contaminated wood – currently a small contributor, lower impact, but could be locally significant. Information through suppliers and retailers of appliances and fuel and at point of sale to discourage the burning of treated wood as fuel, and promotion of waste disposal services.

6. Well constructed bonfires and burning clean wood in the home produce relatively low emissions – these could be promoted as ‘clean’ alternatives, possibly with incentives to purchase in areas where cost might be an issue.

### 7.2 Potential public awareness strategies

In evaluating potential strategies for educating the public to reduce emissions of dioxins and dioxin like PCBs, the first step is to identify the target audience. This will determine appropriate messages and communications channels that have the potential to contribute to behavioural change.

In working towards identifying appropriate communications strategies to discourage the use of bonfires as a method of waste disposal and to encourage minimal polluting bonfires, the following tasks were carried out:

- Desk research looking at current communications strategies used at local level (specifically by local authorities)
- Anecdotal evidence was sought from relevant stakeholders on current perceptions of bonfire problems and the perpetrators
- Recent campaigns that have been undertaken to raise awareness of local environmental issues and change behaviour were examined

A detailed literature review revealed little international work which contained useful information which was relevant to this project. The study therefore focused on research into the effectiveness of environmental awareness work currently being undertaken in the UK, both specifically linked to bonfires and solid fuel burning, and also covering wider environmental issues. This research enabled potentially effective mechanisms for public engagement to be identified, along with an indication of likely budgets.

### 7.3 Current Promotional Activity - Domestic Solid Fuel Combustion

#### 7.3.1 Local Authority View

Currently most locally authorities do not view this as a significant air quality problem. Our research revealed that their main concern is the nuisance impact, and that there are few complaints. Information is reactive – leaflets sent out to complaints rather than perpetrators. Pollution from solid fuel for domestic heating is normally considered to be acceptable – for example in South Derbyshire where free coal goes to ex-employees of the mining industry, there are few complaints.

Recent anecdotal evidence suggests that most local authorities no longer enforce Smoke Control Areas; indeed some have lost the relevant orders and maps. There is likely to be widespread, but diffuse reactivation of SCAs with supporting information, possibly as part of local Air Quality Action Plans, is one option for further promotion.
7.3.2 Manufacturing/Supplier View

In view of Government policy to promote the use of biomass for heating, a campaign here could use a positive message, promoting efficient, economic fuels over inefficient more polluting fuels. This approach could be used both to promote sales of cleaner biomass fuels, and to secure a reduction in emissions of potentially harmful substances.

7.3.3 Who burns domestic solid fuel?

Domestic combustion of solid fuels is concentrated in particular regional areas. In particular, solid fuel use is high in areas with a history of coal mining, and in low income areas where gas-fired central heating is less prevalent, and households are likely to use cheaper, less efficient fuels. Domestic solid fuel combustion is also more likely to occur outside urban areas, where there are no specific smoke controls; there may be a readily available supply of wood; and waste disposal facilities are less accessible.

7.4 Current Promotional Activity - Domestic Waste Burning and Bonfires

7.4.1 Bonfires

Who has bonfires?

Households – particularly items of waste which are not taken, or are charged for disposal, by the local authority. Key problems are large items of furniture, garden waste, DIY waste.

Gardeners – many will not compost garden waste as it may contain seeds, spores, and weeds which may re-sprout. Woody material such as prunings and clippings are also difficult to compost without shredding.

Small businesses – some commercial waste is burnt in back gardens by small businesses to avoid disposal costs. Legally this is commercial waste, but it is disposed of on a garden bonfire or in a crude incinerator.

Local authority view

Of the local authorities who provided information, most do not actively address nuisance related to bonfires – activity is limited to responding to any complaints about bonfire nuisance. Where there is a specific, concentrated problem, some have worked with allotment societies and endeavoured to interest local press in the issue. Many have information on websites, and either produce a leaflet or use leaflets provided by the National Society for Clean Air (NSCA). These focus on nuisance and alternative disposal rather than toxic pollutants.

Gardening Organisations View

Gardening organisations and press are aware of the issue, and periodically encourage alternatives to burning. For example, Garden Organic runs an annual leaf mould campaign, and a good bonfire guide was presented by Bob Flowerdew on Gardeners Question Time in the run up to Bonfire Night 2005.
7.4.2 Domestic waste burning

The following sectors with an interest in domestic waste burning have been approached:

Local Authorities

A selection of local authorities were contacted during the course of this project. The authorities comprised 55 local authorities who have ordered NSCA Bonfire leaflets in the past year; 15 who have bonfire information on their websites; and 15 who, as far as could be established, have no visible information on bonfires. These local authorities were asked:

- What, if any, information they provide for the public on bonfires
- What, if any, impact they feel this has on the number of bonfires

Currently most locally authorities do not view dioxins and furans from domestic combustion sources as a significant air quality problem. There is no requirement under local air quality management regime to tackle these specific pollutants. The main concern of local authorities is the nuisance impact, and relatively few complaints are received. Information is provided on a reactive basis, by sending leaflets to complainants rather than perpetrators.

National Environmental Organisations

A review of recent awareness campaigns, looking at communication channels used, target audience, budget and impact is set out in Table 5 below.

Table 5  Review of recent awareness campaigns

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Campaign</th>
<th>Campaign Objective</th>
<th>Target Audience</th>
<th>Budget</th>
<th>Time/Duration</th>
<th>Channels</th>
<th>Evaluation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Ireland Environment and Heritage Service</td>
<td>National Leaf mould Campaign</td>
<td>To promote leaf composting rather than burning</td>
<td>Gardeners</td>
<td>No dedicated budget</td>
<td>Annual – late summer/autumn, past 7 years</td>
<td>Posters, Leaflets, Regional Press</td>
<td>No comment</td>
<td>Annual, seasonal impact</td>
</tr>
<tr>
<td>Garden Organic</td>
<td>EnCams (Environmental Campaigns)</td>
<td>To raise awareness of who to complain to about noise</td>
<td>Noise sufferers Doncaster, Leeds</td>
<td>£50,000 (estimated)</td>
<td>One month</td>
<td>Radio and billboard advertising targeted at noise sufferer</td>
<td>By number complaints received – increase</td>
<td>One off</td>
</tr>
<tr>
<td>NSCA</td>
<td>NSCA Noise Action Week</td>
<td>To raise awareness of who to complain about noise</td>
<td>England</td>
<td>£100,000</td>
<td>1 week (previously one day) annual</td>
<td>National PR – press, online, radio Local outreach work by volunteer noise specialists</td>
<td>Feedback forms, comments Positive</td>
<td>Annual</td>
</tr>
</tbody>
</table>
7.5 Communications Strategy

In designing a communications strategy, it is important to understand why bonfires are used and what the current perceptions are. More research would be useful to assist in fine tuning campaign messages. The key audience groups noted above are:

- Householders
- Gardeners
- Small businesses

In the long-term, the most effective way of engaging members of the public in reducing emissions of dioxins and dioxin-like PCBs from domestic sources is to render the most polluting activities socially unacceptable. Successful campaigns have been mounted in the past – for example, campaigns to make it unacceptable to travel in a car without a seatbelt, or to drink and drive. Such campaigns would require a sustained investment in a simple, consistent message over a long period of time.

Why have Bonfires?

A number of factors influence the decision to make or maintain a bonfire:

- Convenient method of waste disposal
- Cost free method of waste disposal
- Habit and practice: those who have ‘always had a bonfire’
- Ignorance: those who are unaware of any impacts
- Enjoyment: some people enjoy the experience
- Tradition: Bonfire Night/July marching season in Northern Ireland

Current Perceptions of Bonfires

- Some people, particularly some gardeners, see bonfires as a necessary part of their activities.
- For others, bonfires are unnecessary and cause local nuisance. There is little evidence of specific concern about dioxin emissions (for instance when compared to proposals for waste to energy plant).
- There is a relative lack of understanding about the relevant legislation. Nuisance law is complex, and some people believe that burning is only allowed at certain times.
Bonfires are a seasonal concern, with the major impact in autumn and winter. However most complaints are received in summer, when others are outside enjoying themselves and may be affected by smoke.

**Who needs to be targeted**

**Householder**

Members of the public who burn general waste will be difficult to target, and it may be appropriate to identify target areas. Some areas of the country have arson task forces; it is possible that these are areas where burning and dumping waste is common. Further research would be needed to confirm this. Local waste disposal information campaigns and recycling initiatives could be a useful channel of communication.

**Solid Fuel User**

People who rely of solid fuel can be targeted through fuel outlets and suppliers at local/regional level. The Solid Fuel Association trade body would be a potential partner.

**Gardeners**

Leisure gardeners are relatively easy to target through existing communications channels with gardening organisations, mainstream press, specialist magazines, TV programmes, celebrities, etc. There is potential for a mixture of approaches here: many gardening organisations are aware of the problems and promote alternatives, but there is scope for co-ordination to ensure a coherent targeted message.

**Business Burner**

Small businesses who burn waste because they perceive cost as a barrier to legal disposal. For example: stables burning dung, small tradesmen burning trade waste in the back garden. Many, but not all, will be aware that they are breaking the law. There is clearly potential for a targeted information campaign.

**7.6 What do we need to communicate?**

The key messages to be communicated with regard to different aspects of domestic solid fuel combustion are set out in this section.

A public engagement campaign should address wider issues than simply focusing on dioxins and PCBs. For example, the campaign could highlight the benefits of recycling waste, and the nuisance that can be caused by bonfires.

Campaigns on waste minimisation and recycling are currently prominent, so there is an existing public awareness of waste issues. A public relations campaign on the wider social unacceptability of burning waste could build on this awareness

Conversely, the term “dioxins” is emotive, and is associated with fears about cancer. A campaign focused purely on the issue of dioxins and PCBs could raise unnecessary fears about this issue, and could also raise unfounded concerns regarding the risks to health of burning solid fuels in any context. People who are not familiar with dioxins may find it difficult to identify a simple message that explains the issue in a way that they can understand and trust.
Domestic fuel burning could be tackled through the provision of more accurate information on existing smoke control coverage; better enforcement of existing smoke control legislation; information and advice on appliances and fuels etc.

The key messages can be summarised as follows:

7.6.1 Economy

- Proper waste disposal is perceived as inconvenient and expensive, but the costs of breaking the law are potentially higher.
- Better solid fuels are perceived as being more expensive, but may be more fuel efficient.

7.6.2 Dispel bonfire myths

- There is a common and widespread belief that there are laws about when and where you have a bonfire. For example, the preamble to the recent good bonfire guide produced by Alan Titchmarsh was ‘if you live in an area that allows garden bonfires.’ In fact, there are no such laws or byelaws.

7.6.3 Negative messages to be communicated

The audience can be reminded that:

- Bonfires are unnecessary
- Bonfires are polluting
- Bonfires can annoy neighbours. Permitting an odour or smoke nuisance to affect the occupiers of other premises is not permitted under UK law (the Environmental Protection Act 1990, the Clean Air Act, 1993).
- Burning of trade waste on ‘garden bonfires’ is not permitted under UK law. Burning of trade waste on (for example) construction sites is not good practice, and may well not be permitted depending on the agreements relating to the particular site.
- Bonfires may cause health problems

7.6.4 Positive messages to be communicated

- Composting can in many cases be an economical alternative to burning green wastes
- Re use and recycling is a more responsible way to deal with household wastes, and can benefit all of us.

7.7 Aim of a communications campaign

The overall aim of a communications campaign would be to make unnecessarily polluting bonfires socially unacceptable. To do this, we need to raise awareness of the impacts in an accessible way to the target audiences identified in Section 7.5. above.
The channels listed below could be used together and complement each other, or individually. Method of communication and reach will be dependent on budget.

**Advertising and promotion**

This could be national or regionally targeted at areas identified to have particular problems. As bonfire impact is mostly visual and olfactory – TV and billboard or newspaper advertising would have more impact than radio. This could be backed by displays and advice at DIY stores, garden centres. A strong simple message would need to be identified, which would not be too worthy or patronising. Any campaign would need to be timed to have maximum impact (i.e. when most bonfires occur).

A national launch with celebrity endorsement would help (a number of celebrities were approached during the tendering stages of this project, and some interest was identified). Given sufficient lead in time an appropriate celebrity may be found. For example, a press launch with a bonfire demonstration – good bonfire, bad bonfire, alternatives to bonfire, with pollution monitoring (subject to practicality), together with a celebrity photo opportunity which could kick start a campaign.

**Partnerships**

Use partner organisations to facilitate promotion – DIY chains, garden centres, gardening organisations, PR and editorial for specialist and national/local press.

Using existing campaigns on waste and recycling – this is particularly pertinent in the context of PVC plastics. There are also increasing number of furniture recycling projects which offer an alternative disposal route for large items.

**Information and Advice – national promotion**

As an alternative, or in addition to advertising, advice and guidance can be produced. Currently, the NSCA Bonfire leaflet is distributed, on request, to around 60 local authorities a year. A number of local authorities produce their own information both in print and online. In the last year, the NSCA Bonfire leaflet online has been viewed 2500 times.

**Leaflets**

These could be distributed via gardening organisations, garden centres, DIY stores, local authorities, or with local free advertising newspapers which are delivered to every household in a district.

**Website**

Web based information, while useful, needs to be promoted. It depends on being sought and found – and therefore is not likely to have a wide reach to those having problem bonfires, who are our target audience. It is more likely to be found by those who see bonfires as a problem and are looking for solutions.

**7.8 Campaign Options**

In summary, these can be split into three options for a communications campaign – one of these or a combination could be used. To ensure a communications strategy is effective, some further research into the potential target audience – geographical, social and an indication of optimum time for a campaign would help. The effectiveness of any public relations or awareness campaign can be evaluated
using before and after surveys of sample populations to assess the impact of the campaign.

7.8.1 Schools

One approach would be to get the issue on the curriculum, through a teaching resource – DVD, interactive web based education tools, or teaching pack. This would probably need to link to the science curriculum.

7.8.2 High Budget – wide reach, high impact

An example of a high budget campaign is the £5 million budget for the Recycle Now campaign. This included a National TV/press/billboard advertising campaign, a PR launch with celebrity endorsement supported by information leaflets, and a web-based resource.

7.8.3 Medium Budget - wide reach, lower impact

A typical budget for this type of campaign would be £200,000. A wide reach / low impact campaign would include measures such as the production of leaflets/guidance with distribution to households either nationally, or focused in target areas where there is a particular problem. It may also be appropriate to develop online guidance. This would need further promotion to be fully effective.

7.8.4 Lower Budget – uncertain reach/impact

A typical budget for this type of campaign would be £10,000. A lower budget campaign may include measures such as the production of leaflets/guidance for distribution through local authorities. Its success would be dependent on commitment of individual local authority environmental health/waste management services.

Table 6 Communications Channels – relative reach

<table>
<thead>
<tr>
<th>Channel</th>
<th>Impact</th>
<th>Reach</th>
<th>Cost</th>
<th>Longevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV Advertising</td>
<td>High</td>
<td>National</td>
<td>High</td>
<td>Short Term</td>
</tr>
<tr>
<td>National Press</td>
<td>High</td>
<td>National</td>
<td>High</td>
<td>Short Term</td>
</tr>
<tr>
<td>Advertising</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National PR</td>
<td>High – Low</td>
<td>Uncertain</td>
<td>Low</td>
<td>Short Term</td>
</tr>
<tr>
<td>Editorial</td>
<td>Medium</td>
<td>Limited</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Website</td>
<td>Low</td>
<td>National/Limited</td>
<td>Low</td>
<td>Long Term</td>
</tr>
<tr>
<td>Advice Leaflet</td>
<td>Medium</td>
<td>National/Limited</td>
<td>Medium</td>
<td>Long Term</td>
</tr>
</tbody>
</table>
8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Technical conclusions

Jones and Sweetman (2004) drew the following conclusions regarding emissions of dioxins and furans from the sources under consideration in this report:

- Emissions are difficult to quantify, resulting in inventories with a large uncertainty
- Burning of wood, coal and gas is a seasonally important source
- Detections also in chimney soot, bottom ash and flue emissions from wood/coal burning stoves and fireplaces
- Dioxin and furan amounts vary widely within and between studies (differences over four orders of magnitude as a result of sampling points, design, fuel type, operating conditions, treatment of wood)
- Some studies have reported high dioxin and furan emissions when PCP contaminated wood is burned
- Emissions of dioxins and furans increase when high chlorine fuels are burnt, or fuels with trace metal contaminants.

These conclusions are confirmed in our review. Evidence was found that both combustion conditions and the chlorine/metals content of materials being burnt are important factors in determining the amount of dioxins and dioxin-like PCBs emitted.

8.2 Key sources of dioxins and dioxin-like PCBs

The key sources of dioxins and dioxin-like PCBs identified in this study are:

- Burning of household waste is a key source of emissions of dioxins and dioxin-like PCBs to the atmosphere. It is also likely to be the primary source of dioxins and dioxin-like PCBs in solid residues. The elimination of household waste burning should be the first target of a public information campaign.

- Of the other sources, coal burning is potentially the next most significant. Provision of public awareness, guidance and (potentially) financial support to use low-chlorine fuels and improve combustion conditions should be the second target of a public information campaign.

- Emissions of dioxins and dioxin-like PCBs from bonfires may also be important. Because of the ready access to target audiences (gardening community) and target times (Bonfire Night in the UK and July bonfire season in Northern Ireland), there is also an opportunity for a useful campaign to reduce emissions of dioxins and furans from bonfires.
8.3 Public information campaigns

8.3.1 Introduction

The Partial Regulatory Impact Assessment, Dioxins and Dioxin-like PCBs in the UK Environment states :-

“There does not appear to be any substantial public information providing advice on best practice in fuel choice for domestic fires (e.g. correctly seasoned wood, dried coal), on the use of unsuitable fuel such as preservative treated wood and the hazards associated with burning domestic waste such as plastics”

This conclusion is supported by the research discussed above. We conclude that there is a role for carefully designed public information campaigns. Public information campaigns should be designed to communicate the following three key messages. Potential strategy options for low, medium and high budget campaigns are identified.

Any advice given to the public has to be simple and easy to achieve. Typical domestic solid fuel users will not change the way they operate their appliance. They may however change the fuel they burn. It is in the latter area where advice could be most effective, especially in the messages (i) to use dry fuel, and seasoned wood; and (ii) not to burn household rubbish at all.

A public awareness campaign should be evaluated using before and after surveys of sample populations.

8.3.2 Funding issues

It may be helpful to quantify the potential benefit which could accrue from a successful public information campaign, if possible. For example, a reduction in emissions will result in a reduction in the intake and body burden of potentially harmful dioxins and dioxin-like PCBs of members of the public. This is most likely to be experienced by those burning the fuels and wastes, but because of the persistent nature of these chemicals, will be effective in reducing body burdens and intakes nationally.

A significant proportion of members of the public currently ingest dioxins and furans above the UK Tolerable Daily Intake of 2 pg/kg body weight per day. The cost per patient of treating cancer is of the order of £100,000 per case. If a publicity campaign contributes to the avoidance of a relatively small number of cancer cases, it will in overall terms provide a net economic benefit.

8.3.3 Campaign 1: “Don’t burn household waste indoors or outdoors, and especially not waste containing plastics”

The recommended campaign strategies and their key features are highlighted below:

Campaign 1: Low budget strategy (around £10,000)

- Use existing channels of communication such as local authority officers responsible for existing local waste management information campaigns, and air quality officers responsible for enforcement of Smoke Control Areas and/or Air Quality Management Areas. These officers could be provided with short briefing papers to enable them to communicate the key messages via existing locally established
channels for communication on air quality and waste management issues.

- Circulate generic articles for use in local free newspapers and newsheets.

**Campaign 1 : Intermediate budget strategy (around £200,000)**

- Carry out tasks specified in low budget option above.
- Produce a dedicated information leaflet for distribution by local authorities. Two possible angles could be explored:
  - Providing information about environmentally-friendly waste disposal (in relation to the existing waste management regime) and/or
  - Providing information about existing Smoke Control Areas (informing householders that they live in a SCA and should only burn authorised fuels in approved fireplaces).

The second option would also address unauthorised burning of wood in fireplaces.

- Develop a web resource providing information and advice on responsible handling of domestic waste; the potential hazards to individuals and the wider environment; waste minimisation options; the services available for responsible recycling and disposal

**Campaign 1 : High budget strategy (around £5 million)**

- Carry out tasks specified in low and intermediate budget options above.
- Investigate advertising strategies for targeting particular geographical areas or social sectors where evidence suggests that waste burning may be prevalent. Further scoping would be necessary to establish the most cost-effective options.
- Consider a national campaign in association with one or more environmental NGOs, with launch, celebrity endorsement and a simple message. Fund a campaign team to spread the message via broadcast and print media.

8.3.4 **Campaign 2 : “For people who have coal fires, make sure the fire burns efficiently and choose coal with a low chlorine content”**

The recommended campaign strategies and their key features are highlighted below. This could be supplemented by a limit on the maximum chlorine content of fuels supplied to the domestic sector (see section 8.5.3):

Further research might be helpful to enable soundly-based advice to be prepared on the most effective steps that can be taken to reduce emissions from domestic biomass combustion. However, it will be difficult to persuade users of domestic solid fuels to change their practices, and difficult to verify whether any steps taken have had the desired effect in changing behaviour and/or reducing emissions of dioxins and dioxin-like PCBs.

**Campaign 2 : Low budget strategy (around £10,000)**
Discuss publicity options with Solid Fuel Association. SFA have an interest in promoting smokeless fuels, and their members are in direct contact with domestic coal buyers. There may be low-budget options for making low chlorine fuels available and visible to domestic purchasers via the SFA’s ongoing activities.

Remind local authorities of the wider air quality benefits to be gained by effective enforcement of Smoke Control Areas.

**Campaign 2 : Intermediate budget strategy (around £200,000)**

- Carry out tasks specified in low budget option above.
- Produce leaflet for distribution by SFA members and/or local authorities, with information about existing Smoke Control Areas (informing householders that they live in a SCA and should only burn authorised fuels in approved fireplaces).
- Develop a web resource providing information and advice on the influence of combustion conditions in domestic fires/stoves, and the chlorine content of solid fuels on emissions of dioxins/furans and PCBs. This could provide advice on efficient burning for the householder’s own economic benefit and also to benefit the environment. It could also provide on choosing and purchasing a low-chlorine fuel.

**Campaign 2 : High budget strategy (around £5 million)**

- Carry out tasks specified in low and intermediate budget options above.
- Investigate paid-for publicity strategies for targeting particular geographical areas or social sectors where coal-burning is still prevalent. This would include rural areas generally and old coaling areas – in particular, areas where concessionary coal is still distributed. Further scoping would be necessary to establish the most cost-effective promotional options.

8.3.5 **Campaign 3 : “Don’t burn waste on bonfires – in particular, avoid burning plastics”**

The recommended campaign strategies and their key features are highlighted below:

**Campaign 3 : Low budget strategy (around £10,000)**

- Use existing channels of communication such as local authority officers responsible for existing local waste management information campaigns. These officers could be provided with short briefing papers to enable them to communicate the key messages via existing locally established channels for communication on air quality and waste management issues.

Circulate generic articles for use in local free newspapers and newssheets, focusing in particular on the late summer / early autumn.

**Campaign 3 : Intermediate budget strategy (around £200,000)**

- Carry out tasks specified in low budget option above.
EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES

- Work with public bodies (such as the Local Government Association) and the voluntary sector (for example the National Council for Voluntary Organisations; Rotary; scouts/guides organisation) to remind organisers of major bonfire events about low pollution options. Produce information leaflets, and possibly a web resource to support this. Other potential partners include the National Campaign For Firework Safety Forum, and the Chief Fire Officers' Association.

- Work with National Society of Allotment and Leisure Gardeners, Royal Horticultural Society, Garden Organic (also known as Henry Doubleday Research Association) and other gardening organisations to network information.

- Produce information leaflets, and possibly a web resource to support liaison with third parties. This would provide information and advice on the environmental effects of bonfires, including issues associated with air and land pollution due to dioxins and dioxin-like PCBs; suitable and unsuitable materials for bonfires; building a good bonfire; good practice before, during and after the event to minimise the risk of pollution.

Campaign 3 : High budget strategy (around £5 million)

- Carry out tasks specified in low and intermediate budget options above.

- Develop and promote a good bonfire guide, with a launch and celebrity endorsement, backed by an advertising campaign. Fund a campaign team to spread the message via broadcast and print media.

8.4 Public information campaigns – example advice

A public campaign was carried out in California aimed at reducing pollution from existing (traditional) fireplaces :-

- Burn only well seasoned wood.

- Burn hardwoods, minimise burning of softwoods.

- Never burn wastes (plastics, glossy or coloured paper, or scrap wood that has been preserved, painted or stained)

- Make sure the fire is hot and has good air flow. Don’t try to choke it down

This kind of simple advice is a useful basis for a public information campaign. Additional points which may need to be covered are:

- Do not burn household waste – dispose of it properly.

- Never burn coal on a wood grate and vice versa. Coal should be burnt on a grate with holes in it, to allow air to pass through, whereas wood should be burnt on a solid plate.

- For wood, allow ash to build up in the base of the fire.

- Burn thin logs, especially when building up the fire to obtain an ash bed and charcoal.
EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES

- Make sure the fuel is kept dry.
- Clean the flue passageways and chimney to remove soot.
- Dispose of the ash carefully and never use as a soil conditioner, especially in the fruit and vegetable garden.

Specific advice on combustion conditions could usefully be linked to local or national advice on waste disposal – for example, Waste Resources Action Plan (WRAP) guidance on disposal of contaminated wood waste (WRAP, 2004).

8.5 Recommendations

8.5.1 Public information campaign

We recommend firstly that Defra carry out a public information campaign, focusing on the three key messages discussed in Section 8.3 above. A range of campaign strategy options are set out in Section 8.3.

- **Campaign 1**: “Don’t burn household waste indoors or outdoors, and especially not waste containing plastics”
- **Campaign 2**: “For people who have coal fires, choose coal with a low chlorine content, and make sure the fire burns efficiently”
- **Campaign 3**: “Don’t burn waste on bonfires – in particular, avoid burning plastics”

Alongside public engagement campaigns, more rigorous enforcement of legal restrictions on bonfires (e.g. relevant provisions of the Environmental Protection Act 1990, and the Clean Air Act, 1993) may also be a useful step in reducing emissions of dioxins and furans from open burning of wastes at domestic properties, construction sites and other premises. This could take the form of exemplary prosecutions, as well as ensuring that adequate alternative waste management facilities are available.

8.5.2 Other research recommendations

Alongside the recommended public engagement strategy, we recommend that further scientific research would also be useful to develop and refine our understanding of emissions of dioxins and dioxin-like PCBs to air from domestic sources.

- We recommend that a series of experiments to evaluate the significance of burning seasoned wood compared to unseasoned wood would be helpful. It seems likely that the more efficient combustion which can be achieved with seasoned wood will give rise to lower emissions, but this was not supported by the data from the literature review. Experimental work under controlled conditions may assist in understanding this issue more clearly and giving better support to a public information campaign.
- It also seems reasonable to expect anthracite and smokeless fuels to give rise to lower emissions than combustion of bituminous coals. Again, this was not clearly supported by the evidence obtained from the
review, and a controlled experiment may assist in clarifying the advice that can be given to consumers.

- In view of the wide spread of information on dioxin emissions from domestic combustion, it is recommended that Defra consider commissioning a wider test programme to determine dioxin emissions from a typical open fire and from a typical closed appliance representative of typical UK appliances. These tests should cover burning coals representative of current UK domestic coal supplies; dry and wet fuels; and for wood, freshly felled and properly seasoned logs.

This information could be used to establish more reliably the relative importance of coal-based fuels and wood to the dioxin inventory and whether their combined contribution to the inventory merits significant effort being made to reduce emissions from these sources.

### 8.5.3 Policy recommendations

It is recommended that Defra maintain a watching brief on the use of pellet burning stoves. The use of potentially contaminated recycled wood to manufacture pellets for domestic use would risk resulting in increased emissions of dioxins and dioxin-like PCBs, together with other potentially harmful substances. If the amount of pellets used increases significantly, then consideration should be given to the regulation and inspection of pellet quality to ensure that clean materials are used.

The costs of household and commercial waste disposal are likely to increase in the future. If household waste collection is charged by mass or volume rather than as a component of Council tax, this could increase the incentive to burn waste in order to reduce the amount requiring collection and disposal. It is recommended that Defra take all necessary steps to limit and reduce the amount of waste burnt in the home, as set out in Section 8.5.1 above. These controls should be built in to any programme which will result in a significant increase in the costs of waste disposal, and particularly any programme where a “pay-per-kilogram” scheme for waste disposal is planned.

Finally, it is recommended that Defra consider limiting the chlorine content of solid fuels supplied to the domestic sector. As well as reducing emissions of dioxins and dioxin-like PCBs, this would also reduce the amount of acidic hydrogen chloride in the flue gases, resulting in improved durability of lower grade steel flues. The potential costs and benefits of limiting emissions in this way could be readily evaluated, and this may prove to be a practical measure in a sector which would otherwise be hard to control.
9. REFERENCES


Clear Skies (2005), website provided by Department for Trade and Industry and BRE http://www.clear-skies.org/manufacturers/RecognisedProducts.aspx


Department for Environment, Food and Rural Affairs (2005), “Review of the Effect that Bonfire Smoke has on Statutory Nuisance Complaints", Confidential draft report

Department for Environment, Food and Rural Affairs (2003) , “Cost curve study”


Department for Environment, Food and Rural Affairs, “Partial Regulatory Impact Assessment – Dioxins and Dioxin-like PCBs in the UK Environment,” 2002

EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES


Douben, PET, Chemosphere, 34, 5-7, 1181-1189 (1997)

Dyke, P. Coleman, P.; James, R., Dioxins in Ambient Air, Bonfire Night 1994, (1997) Chemosphere v34, n5-7, p1191


Gullett BK; Touati A; Hays MD (2003), PCDD/F, PCB, HxCBz, PAH, and PM emission factors for fireplace and woodstove combustion in the San Francisco Bay region, US EPA, National Risk Management Research Lab, Environmental Science and Technology, Vol 37, No.9, 1758-1765


Hutzinger, O. Fiedler, H (1988), Emissions of Dioxins and Related Compounds from Combustion and, Incineration Sources, (Final rept), NATO Committee on the Challenges of Modern Society, Brussels (Belgium), Bayreuth Univ.(Germany, F.R.). Report No.: CCMS-172; EPA/600/6-90/013, Aug 88 (219pp)


Nakao, T; Aozasa, O; Ohta, S; Miyata, H (2002), Formation of Dioxin Analogs by Open-Air Incineration of Waste Wood and by Fire of Buildings and Houses Concerning Hanshin Great Earthquake in Japan, Setsunan University, Osaka, Japan; Chemosphere v46, n3, p429(9)


Neurath, C (2004). “PVC’s role in dioxin emissions from open burning; new analysis of EPA data”, Organohalogen Compounds vol66 pp1146 - 1152


EMISSIONS OF DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS FROM DOMESTIC SOURCES

APPENDICES
1. METALS LEVELS IN TREATED WOOD WASTE

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>EPF Level</th>
<th>German Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>25 mg/kg</td>
<td>2 mg/kg</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>50 mg/kg</td>
<td>2 mg/kg</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>25 mg/kg</td>
<td>30 mg/kg</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>40 mg/kg</td>
<td>20 mg/kg</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>90 mg/kg</td>
<td>30 mg/kg</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>25 mg/kg</td>
<td>0.4 mg/kg</td>
</tr>
<tr>
<td>Fluorine (F)</td>
<td>100 mg/kg</td>
<td>100 mg/kg</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>1000 mg/kg</td>
<td>600 mg/kg</td>
</tr>
<tr>
<td>PCP</td>
<td>5 mg/kg</td>
<td>3 mg/kg</td>
</tr>
<tr>
<td>Creosote</td>
<td>0.5 mg/kg</td>
<td>- mg/kg</td>
</tr>
</tbody>
</table>
2. SUPPORTING INFORMATION ON SOLID FUEL USE IN THE UK RESIDENTIAL SECTOR

A2.1 Introduction

This appendix provides supporting information on the UK market for solid fuel use in UK households in terms of solid fuel types and appliances used. It also gives information on the chlorine content of these fuels and describes how the fuels burn on the various appliances, in particular whether conditions are conducive to dioxin formation.

A2.2 Legislation affecting Solid Fuel Combustion in the Residential Sector

The system of legislation in the UK to control air pollution has evolved from 1863 to the present day. The Alkali Act (1863) required arrestment of offensive emissions of chemicals – but not smoke – from alkali works. Control of smoke emissions from industrial and domestic premises did not become a major issue until the late 1950s when it was shown that a large number of deaths in UK cities were directly attributable to air quality. This led to a succession of Clean Air Acts from 1956 to 1993, leading to the current situation whereby householders and small industrial users, in certain prescribed areas, can only burn solid fuels if they do so “cleanly”. It is believed that control of smoke emissions also helps to reduce the emissions of a wide range of pollutants including sulphur, PAHs, dioxins and furans.

Thus users of solid fuels in the prescribed areas, referred to as “Smoke Control Zones” must either burn authorised smokeless fuels or use approved (exempted) appliances. The impact on the market has seen a switch from bituminous coal towards smokeless fuels and, more importantly, an abandonment of solid fuel combustion in favour of gas.

A2.2.1 Smoke control zones

Under the Clean Air Act (1993), local authorities may declare whole or part of their district to be a smoke control zone. It is an offence to emit smoke from a chimney in such a zone and an offence to acquire an unauthorised fuel unless it is used in an exempt appliance. Generally, urban areas are those which are subject to the smoke control limitations. About 50% of all households in the UK are in smoke control zones.

A2.2.2 Authorised fuels

Authorised fuels are fuels which have been authorised by Statutory Instruments made under the Clean Air Act (1993). Authorised solid fuels include anthracite and dry steam (low volatile) coal, which are inherently “smokeless” and a range of manufactured smokeless fuels, predominantly briquettes, which have been shown to burn with low smoke levels in standard combustion tests on an open fire. There are separate lists of authorised fuels for each country of the UK.

A2.2.3 Exempted appliances

Exempt appliances are those stoves, boilers, room heaters, wood burners and ovens which have been exempted by Statutory Instruments under the Clean Air Act (1993). Again, they have passed tests to show that they burn unauthorised fuels.
with low smoke emissions. There are separate lists of exempted appliances for each country of the UK.

A2.3 Fuels

A2.3.1 Fuel types

Table 7 lists a broad classification of the range of fuels burned in the UK residential sector. Table 7 also gives indicative smoke emissions from these fuels when tested under standardised conditions on an open fire, as specified in British Standard BS3841.

Table 7  Solid fuels in the household market and indicative smoke emissions

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Indicative smoke emission, g/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous coal</td>
<td>30-40</td>
</tr>
<tr>
<td>Natural smokeless fuel</td>
<td></td>
</tr>
<tr>
<td>Anthracite</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Dry steam</td>
<td>2-3</td>
</tr>
<tr>
<td>Manufactured smokeless fuel (MSF)</td>
<td></td>
</tr>
<tr>
<td>Briquettes</td>
<td>1-5</td>
</tr>
<tr>
<td>Coke</td>
<td>1</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Manufactured fuel – non-smokeless briquettes</td>
<td></td>
</tr>
<tr>
<td>Bituminous coal briquettes</td>
<td>30-40</td>
</tr>
<tr>
<td>Brown coal briquettes</td>
<td>10-15</td>
</tr>
<tr>
<td>Wood</td>
<td></td>
</tr>
<tr>
<td>Logs</td>
<td>20-30</td>
</tr>
<tr>
<td>Manufactured logs (wood/wax)*</td>
<td>3-5</td>
</tr>
</tbody>
</table>

* Different test conditions, so not directly comparable with other test results

Nowadays, bituminous coal and anthracite used in the UK market are not just from indigenous sources. Coals from Poland, Columbia, South Africa and many other countries are sold in the UK market, as are anthracites from China and Vietnam.

Similarly the feedstocks for briquettes are not confined to UK sources. Most MSF briquettes are predominantly made from anthracite but with varying proportions of petroleum coke and bituminous coal. Most of the MSF briquettes sold in the UK are bound by molasses and subsequently heat-treated at the briquetting works to 250-300°C in order to harden them and render them water resistant. However, some briquettes are bound with starch and similarly heated immediately after manufacture, and some briquettes are made by processes using cold cure resin binders.

Lump petroleum coke used directly in domestic fuel blends and the fine material forming part of certain briquetting blend feedstocks, predominantly comes from the Long Beach facility in California.
Most of the coke supplied to the UK domestic market is high temperature coke produced in by-product coke ovens. The exception is a few sales from residual stocks held by merchants of Coalite, following the closure of the Coalite manufacturing plant. Coalite is properly described as a low temperature coke, although it was traded as a “smokeless coal”.

The are small markets for brown coal briquettes, made in Germany, and bituminous coal briquettes, made in the UK. Neither fuel is designated smokeless.

Finally, the wood market is served mainly by natural logs but also by (i) manufactured, usually packaged, extruded logs made from sawdust, wood fibres and wax and (ii) manufactured pellets, made from sawdust. The wood fuel market is described in greater detail in Section A2.3.2.

A2.3.2 Market

Mineral solid fuels

The market for mineral fuels has consistently declined in the last fifty years. When the first UK Clean Air Act was passed in the mid 50s, the market for domestic coal use was about 25 million tonnes per year. Table 8 shows how the market has declined to a fraction of this former value in recent years and continues to fall (DTI Digest of UK Energy Statistics, 2005).

Table 8 Mineral solid fuel consumption in UK households (million tonnes per year)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2.59</td>
<td>2.37</td>
<td>2.52</td>
<td>1.90</td>
<td>2.36</td>
<td>1.80</td>
<td>1.21</td>
<td>1.36</td>
</tr>
<tr>
<td>MSF briquettes</td>
<td>0.58</td>
<td>0.60</td>
<td>0.55</td>
<td>0.50</td>
<td>0.45</td>
<td>0.39</td>
<td>0.34</td>
<td>0.30</td>
</tr>
<tr>
<td>Coke</td>
<td>0.08</td>
<td>0.12</td>
<td>0.1</td>
<td>0.13</td>
<td>0.07</td>
<td>0.18</td>
<td>0.13</td>
<td>0.05</td>
</tr>
</tbody>
</table>

In Table 8, coal is taken to refer to all types of bituminous coal and anthracite, with the split between these two categories in 2004 being:

- Bituminous coal: 0.79 million tonnes per year
- Anthracite: 0.57 million tonnes per year
- Total: 1.36 million tonnes per year

The reliability of these data is, however, open to question. The domestic sector is often used to balance fuel use estimates because of the small market and the lack of a realistic means of estimating the quantity of screenings of household coal being transferred to other markets, and vice-versa. Table 9 compares the DTI data for 2001 against data supplied by the Solid Fuel Association (2005).
Table 9  Comparison of DTI and SFA estimates of solid fuel sales in UK households in 2001

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous coal</td>
<td>953</td>
<td>817</td>
<td>530</td>
</tr>
<tr>
<td>Anthracite</td>
<td>1413</td>
<td>1212</td>
<td>785*</td>
</tr>
<tr>
<td>MSF briquettes</td>
<td>446</td>
<td>382</td>
<td>248*</td>
</tr>
<tr>
<td>Coke</td>
<td>67</td>
<td>57</td>
<td>37*</td>
</tr>
<tr>
<td>Total</td>
<td>2879</td>
<td>2469</td>
<td>1600</td>
</tr>
</tbody>
</table>

Note *: tonnages for fuel types derived by assuming same proportions as in DTI figures

It can be seen that there is a relatively wide spread of values. On balance, the SFA total estimate is likely to be closer to the actual value. Adjusting the 2001 SFA total to 2004, by assuming the faster rate of decline in the non-smokeless market, as indicated by the DTI figures, the current market is estimated to be:-

- Bituminous coal: 0.45 million tonnes per year
- Anthracite: 0.30 million tonnes per year
- MSF briquettes & coke: 0.35 million tonnes per year
- Total: 1.11 million tonnes per year

**Wood**

In contrast to the declining market shown in Tables 2 and 3, for mineral solid fuels, the wood market in the same sector has been static or has increased. The DTI Energy Statistics estimate of wood combustion in 1990 was 174 kilotonnes oil equivalent, rising to 204 kilotonnes in 2004 (DTI, 1995). These figures equate to about 495 and 580 kilotonnes per year of wood of calorific value 15,800 kilojoule per kilogramme (gross)

Enquiries made to the DTI and Defra have indicated that there is a lack of confidence in the published figures for wood consumption. The figures probably relate to the consumption of commercially traded wood rather than taking account of all the possible sources of wood.

Investigations of the quantities of wood burned in the domestic sector in Great Britain in 2004 gave an estimate of 1 million tonnes per year, with an estimated uncertainty of +/- 0.1 million tonnes per year, for wood legally sourced and burned, comprising:

- Logs purchased from firewood merchants or other fuel merchants
- Logs acquired as a result of arboriculture
- Logs sourced from the householder’s own land or land upon which the householder has formal collection rights
The estimate excludes those who may burn wood in smoke control zones, mainly occasional users at winter weekends and Christmas/New Year.

The wood market can be divided into three categories:-

- A small core of primary heating users who typically consume 8 to 10 tonnes/year of wood logs (based on an assumed calorific value of 15,800 kJ/kg as fired). These amount to less than 10% of the households who are “wood fuel users”.

- A substantial secondary heating market, comprising about 90% or more of “wood fuel users” who burn between 1 and 2 tonnes per year and whose primary heating is usually by oil, although occasionally by LPG or natural gas.

- A numerically large (but in tonnage small) number of true occasional users, who have a wood fire which they use no more than 12 times/year, each consuming less than 100 kg/year.

There are no large organisations supplying the wood fuel market: most wood suppliers are sole trader, partnership or family businesses, often concerned with forestry. Sales are usually by the “load” to avoid the need to consider moisture content, although a “load” is usually taken to mean 1 tonne of wood logs.

As intimated with the moisture content issue, sales of wood are not always of seasoned logs immediately fit for burning. Freshly felled timber can contain up to 60% moisture if coniferous, such as pine, and 45% if deciduous (broad-leaved) such as beech. It is important for efficient burning that logs are stored (seasoned) over winter (e.g. felled in winter for the following winter’s fuel) preferably on a sunny and covered site. Seasoning reduces moisture contents to 20-25% and this can be reduced further to approximately 15%, by allowing the logs to “dry” in the house for a few weeks before burning.

Some years ago, the Forestry Commission produced an excellent leaflet to explain the importance of the seasoning of wood to achieve maximum performance on the fire. However, this useful advice is not always heeded by householders. This leaflet pointed out that inefficient burning can lead to tar formation, which may be an indicator of increased risk of dioxin formation.

At the special wood fuel end of the market the tonnage of wood chips and pellets sold for combustion in 2004 is considered to be very small, although there is now quite a large list of registered pellet stoves and boilers (Clear Skies, 2005). Domestic fuel sales are not likely to be more than a few thousand tonnes per year, but these are likely to increase significantly in the next few years.

**Overall market for solid fuel in 2004**

From the above, and other, analyses, Table 10 sets out the most likely tonnages of solid fuels sold in the domestic market in 2004.
Table 10  Estimated solid fuel market in 2004

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Fuel sold in 2004 (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Logs</td>
<td>1.00</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>0.45</td>
</tr>
<tr>
<td>Anthracite</td>
<td>0.30</td>
</tr>
<tr>
<td>Smokeless + coke</td>
<td>0.35</td>
</tr>
<tr>
<td>Total</td>
<td>2.10</td>
</tr>
</tbody>
</table>

The estimated ratio of tonnages within and outside smoke control zones is based upon:-

- The very modest number of current smoke-reducing ("exempted") appliances
- The relatively high cost of manufactured smokeless fuel
- The small use of anthracite in gravity feed boilers
- The preponderance of gas in smoke control zones
- The supply of 150,000 tonnes per year of concessionary fuel
- The experience and judgement of Gastec

A2.4 Appliances

A2.4.1 Types

Solid fuel appliances can be conveniently broken into four broad categories:-

- Open fires
- Closed appliances
- Cookers
- Gravity fed boilers

Each of these categories is addressed with reference to their performance and current usage.

Open fires

Open fires with chimneys have been used in the UK for hundreds of years. They range from large inglenooks to the more conventional 18 inch-wide (occasionally as low as 14 or 16 inch) openings, which were a feature of almost all pre-1960 houses. Traditionally this was the main source of heat in a room but now open fires are
increasingly being used as a supplementary heat source. However, for many households the fire is still considered to be the focal point to a room. Bituminous coal and wood burns with an attractive long, flickering yellow flame, and many people enjoy the appearance of an open fire, and the opportunity to tend the fire.

The efficiencies (defined as useful heat output as percentage of heat input) of these appliances are relatively low, achieving no more that 35% with smokeless fuel and 25% with bituminous coal for open fires without back boilers (water jackets). Inglenook fires have lower efficiencies when burning wood (as low as 15%). This is a result of operation at very high excess air ratios. These high ratios are not combustion requirements but rather are needed to ensure that the smoke goes up the chimney rather than into the room.

From about 1965, considerable effort was directed in the UK to improving the efficiency of open fires by designing high output boiler back (HOBB) units, to give hot water and central heating. HOBBs surround the fire bed with a water jacket and are designed to force the products of combustion through a restricted throat at the back of the appliance where heat is transferred to the water. Efficiency can then increase to 65%.

In smoke control zones, most householders will burn MSF briquettes with anthracite or coke perhaps being used for banking, e.g. overnight. Of course, in the non-controlled, mainly rural areas, the householder is free to use any fuel, provided that no nuisance is caused. On cost grounds, this is usually bituminous coal and/or wood.

**Closed Appliance**

A closed appliance is ideal for heating a single room using solid fuel. If correctly designed, installed and operated, a closed appliance should be efficient and thermostatically controllable. The appliance may or may not have a transparent or translucent window through which the fire can be observed. The appliance may also be fitted with a hot water boiler to provide central heating.

Closed appliances are either designed to fit into a standard fireplace opening (in which case they are often known as roomheaters) or to be free-standing (in which case they are usually known as stoves).

Conventional roomheaters, originating from 1960s designs, normally burn larger anthracite lumps, MSF briquettes or coke. Free-standing stoves are normally designed to burn wood logs only or are multifuel appliances (with different grate arrangements according to whether wood or mineral fuels are used).

With most closed appliances burning non-smokeless fuels, tars and other pollutants are emitted from the chimney, especially after refuelling. Some closed appliances do not burn in this upburning mode, but in a downburning mode. This means that the tars are consumed within the hot zone of the fire and emissions from the chimney are reduced by a factor of up to 10. Downburners are exempted appliances and can be used with bituminous coal, wood or manufactured fuels.

There is an embryonic market in the UK for a range of boilers and stoves designed to burn only wood pellets and/or wood chips. The market is better established in the US, Austria and Scandinavia. This market was stalled in the UK for many years because of a familiar problem – there were no pellets available in the UK to drive the appliance market, and no appliances to drive the marketing of pellets. However, initiatives and various incentives by and for both pellet manufacturers and appliance suppliers are starting to generate a market. Because of the
environmental benefits of using a renewable fuel, the use of pellets/wood chips is likely to grow significantly in the next decade.

**Cookers**

Range type cookers, which often also provide central heating, remain popular in country districts. Traditionally they were fired by solid fuel, but, for convenience – not least for control of cooking temperatures – oil and gas fired range cookers predominate present-day sales.

Gas paths in cookers tend to be complex and easily blocked by the smoke produced by bituminous coal. This makes anthracite or MSF the preferred choice for many people although, there are multi-fuel cooker designs which allow for the use of the complete range of solid fuels except petroleum coke.

The market for cookers is small.

**Gravity fed boilers**

The gravity fed boiler, fed by anthracite grains or beans, offers a high level of automation and cleanliness. They gained in popularity in the 70s and 80s but the numbers in use have declined in recent years, with current sales being very low.

**A2.4.2 Numbers of appliances**

The 2001 English House Condition Survey by Defra/MORI (2001) estimated the number of primary heating appliances in the GB as 384,000 solid fuel appliances capable of providing full central heating, with a further 126,500 stoves providing space heating only. These figures exclude secondary heating appliances.

Current sales of closed wood burning and multifuel appliances are about 56,000 per year (source SFA). This number has remained broadly constant for many years. Assuming a 20-year life for this type of appliance this would give a total inventory of 1,120,000 closed fuel burning appliances (as distinct from open fires).

Separate analyses by GfK (1997) estimated that there were 2.7 million fireplaces in which solid fuel could be burned and, separately, a total estimate of the solid fuel secondary market of 1.6 million homes. This is in broad agreement with data from the Domestic Energy Fact File (Defra, 1998) which estimated 1.4 million homes in the UK using solid fuel as the primary source of heating.

Inconsistent definitions of primary and secondary heating undoubtedly complicate the picture but overall Gastec estimates that the numbers of the present housing stock with solid fuel heating capabilities to be as shown in Table 11. While Table 11 does not account for cooker and gravity feed appliances, the total of these is considered to be very small.
### Table 11: Estimate of the Solid Fuel Appliance Market

<table>
<thead>
<tr>
<th>Appliance</th>
<th>User</th>
<th>Number (000s)</th>
<th>Annual coal equivalent (million tonnes per year)</th>
<th>Total coal equivalent (million tonnes per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>Primary – full central heating</td>
<td>384</td>
<td>3.4</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>Primary - stove</td>
<td>126</td>
<td>2.0</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>600</td>
<td>0.8</td>
<td>0.48</td>
</tr>
<tr>
<td>Open fire</td>
<td>Secondary</td>
<td>350</td>
<td>0.8</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Occasional</td>
<td>700</td>
<td>0.05</td>
<td>0.035</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>2.35</td>
</tr>
</tbody>
</table>

### A2.5 Propensity for fuels to produce dioxins

#### A2.5.1 Background and general considerations

Douben (1997) estimated that the sources of dioxins in the UK in 1995 included those shown in Table 12.

### Table 12: Emissions of dioxins and dioxin-like PCBs to air in the UK (1995)

<table>
<thead>
<tr>
<th>Process</th>
<th>Estimated emission (g ITEQ per year)</th>
<th>Quality of data and estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Domestic coal combustion</td>
<td>20</td>
<td>34</td>
</tr>
<tr>
<td>Domestic wood combustion</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>560</td>
<td>1100</td>
</tr>
</tbody>
</table>

The estimates of emissions from domestic wood combustion were the same as those used by Alcock et al. (1999), following Eduljee and Dyke (1996).

Thus, although the quality of the data for solid fuel combustion in the domestic sector was considered to be poor, it was believed that 4-5% of total emissions of dioxins were attributable to such combustion, with coal combustion contributing a larger proportion than wood. Furthermore the data indicated that the future contribution to the inventory from domestic coal and wood burning would increase to up to 15% as the significance of other sources declined.

The Defra Partial Regulatory Impact Assessment (Defra, 2002) estimated dioxin emissions from domestic burning in 1999 at 3% of the total of 345g ITEQ; that is, 10.4 g ITEQ per year. This was a relatively small proportion of the emissions from accidental fires and open burning, which were estimated at 25% in total. The 3% figure is in broad agreement with the figure of 2% estimated by Lee et al (2005) (proportion of total emission from domestic burning of coal and wood). However,
other reports quote a contribution from domestic sources of 8-24% and ~20% of the UK total for 1996 and 1998 respectively (Alcock et al., 1999; NAEI, 2005).

The European Dioxin Inventory (European Commission, undated) estimates emissions of dioxins and furans from the UK residential sector to be between 1 and 29 µg ITEQ per tonne of clean wood, 10 – 50 µg ITEQ per tonne of treated wood and 0.7 – 9.3 µg ITEQ per tonne of coal.

Thus it is clear that there is a lack of definitive data concerning both the absolute emissions of dioxins from the domestic burning of coal and wood (when considered as separate fuels), and the total percentage contribution to the overall inventory. Furthermore, domestic burning may in some cases be limited to considerations of combustion of fuels inside the house for heating purposes whereas a broader definition can also be used to include the outdoor burning of household and garden waste.

A2.5.2 Mechanisms of dioxin and dioxin-like PCB formation

In this section, the conditions likely to be conducive for dioxin formation are considered in the light of the conditions experienced in solid fuel combustion in the domestic sector. Dioxin formation and destruction reactions are complex but a number of factors affect dioxin formation and releases:

**Chlorine content of fuel**

All else being equal there appears to be a positive relationship between the chlorine content of the fuel and the levels of dioxins and dioxin-like PCBs formed.

**Oxygen dependence**

Molecular oxygen must be present in the gas stream to form dioxins. However, the relationship is complex because dioxins are partial oxidation products of the elements. In the presence of higher oxygen levels, oxidation is more likely to proceed nearer to completion, which would tend not to favour the formation of low-oxygen intermediates such as dioxins and furans. The dependence on oxygen levels is also likely to be affected by the presence of oxygen in the fuel itself.

PCBs do not contain oxygen, and their formation is likely to be favoured by low oxygen conditions, other factors being equal.

**Catalyst dependence**

Copper ions appear to have a strong catalytic effect on dioxin formation. Other transition metal ions have a lesser catalytic effect.

**Carbon gasification**

Dioxin formation has been shown to be closely related to low-temperature carbon gasification (Huang and Buekens, 1996).

**Turbulence**

There is some evidence to suggest that dioxin emissions are reduced by reducing turbulence in the hearth. This may be due to reduced opportunities for solid-gas reactions under these conditions. At the same time, dioxin emissions are reduced by increased turbulence in the secondary burning zone, which may be as a result of
reduced opportunities for any dioxins and furans present to pass through the secondary combustion zone without oxidation.

**Steam**

There is some evidence to suggest that steam increases dioxin formation.

**Temperature**

Temperature of the combustion gases is perhaps the single most important factor in forming dioxin-like compounds. Temperatures typically ranging from 200-500°C, especially in the presence of very fine particles with high surface area (e.g. fly ash) are most conducive to their formation, with maximum formation occurring at about 350°C.

**Sulphur**

There is some evidence to suggest that sulphur compounds (SO₂) reduce dioxin formation. This occurs either by preferential reaction with any metal catalysts which may be present, or by depleting any chlorine radicals present in the combustion process.

**Overall conclusion**

Factors affecting dioxin formation include chlorine levels in the fuel, temperatures (especially in the post combustion zone), residence times, oxygen concentrations, combustion efficiency, ash chemistry and turbulence. The combination of these factors results in a wide variability in dioxin and dioxin-like PCB emissions, even from similar situations and processes.

**A2.5.3 Chlorine content**

In view of the link between chlorine contents of fuels and the dioxin levels produced, the ranges and typical chlorine contents of fuels and other materials which could be combusted by householders are set out in this section.

Table 13 shows that the chlorine contents of coal, peat and wood cover a wide range of values.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Cl content</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range, ppm</td>
<td></td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>0-17000</td>
<td>50-2000</td>
</tr>
<tr>
<td>Peat</td>
<td>20-1500</td>
<td>20-200</td>
</tr>
<tr>
<td>Wood Chips</td>
<td>300-1000+</td>
<td></td>
</tr>
</tbody>
</table>

Table 14 has been derived from a single source (Energy Research Centre of the Netherlands (ECN), 2005; [www.ecn.nl/phyllis](http://www.ecn.nl/phyllis)) and gives data mainly from single samples. Thus the results given for a particular category should not necessarily be taken to be representative of typical moisture and chlorine contents of that source of material. Nevertheless, a few general observations can be made :-
The chlorine contents of coal are generally higher than for clean wood, e.g. natural wood logs.

Contaminants in various sources of waste wood can result in significant increases in chlorine content, bringing the levels to a similar value found for many coals.

Other wastes, which may be burned by householders, either in household appliances or on bonfires, generally have higher chlorine contents than clean wood.

The chlorine content of PVC is two orders of magnitude higher than most coals and clean wood.

<table>
<thead>
<tr>
<th>Table 14</th>
<th>Chlorine and moisture contents of a range of fuel and other samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Moisture %</td>
</tr>
<tr>
<td>Coals and anthracite</td>
<td></td>
</tr>
<tr>
<td>Anthracite</td>
<td>2.9</td>
</tr>
<tr>
<td>Average of coal in NL 1998</td>
<td>13.7</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>6.2</td>
</tr>
<tr>
<td>Columbian</td>
<td>12.1</td>
</tr>
<tr>
<td>Indonesian</td>
<td>5.2</td>
</tr>
<tr>
<td>Polish</td>
<td>A2.3</td>
</tr>
<tr>
<td>South African</td>
<td>14.4</td>
</tr>
<tr>
<td>US – Illinois No 6</td>
<td>13.2</td>
</tr>
<tr>
<td>UK – Hem Heath</td>
<td>5.1</td>
</tr>
<tr>
<td>UK – Daw Mill</td>
<td>12.8</td>
</tr>
<tr>
<td>Low rank coals</td>
<td></td>
</tr>
<tr>
<td>S Australian</td>
<td>11.6</td>
</tr>
<tr>
<td>Indonesian</td>
<td>7.2</td>
</tr>
<tr>
<td>Brown</td>
<td>6.2</td>
</tr>
<tr>
<td>Peat</td>
<td>5.4</td>
</tr>
<tr>
<td>Finnish</td>
<td>7.5</td>
</tr>
<tr>
<td>Young surface</td>
<td>2.7</td>
</tr>
<tr>
<td>Wood</td>
<td></td>
</tr>
<tr>
<td>Bark</td>
<td>3.3</td>
</tr>
<tr>
<td>Beech chips</td>
<td>1</td>
</tr>
<tr>
<td>Demolition</td>
<td>2.1</td>
</tr>
<tr>
<td>Demolition, painted</td>
<td>2.1</td>
</tr>
<tr>
<td>Residues with adhesives</td>
<td>0.9</td>
</tr>
<tr>
<td>Waste</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>1.4</td>
</tr>
</tbody>
</table>
There is considerable variation in chlorine content of UK coals. For example, many Midlands coals have a relatively high chlorine content. In contrast the anthracites and low volatile coals of South Wales have low chlorine contents, more typical of that shown for anthracite in Table 14.

As noted above, the majority of the MSF market in the UK is provided by briquettes made using molasses as a binder. Cane molasses is one such feedstock, which at a typical solids content of 75%, has a chlorine content (as chloride) ranging from 0.7 – 3.0% (typically 1.5%). The feedstock fed to the briquette presses contains up to 15% by weight molasses. Although the heat-treatment of the green briquettes at the briquettng works removes some of this chlorine, a significant proportion may remain in the fuel. Anecdotal evidence indicates that the chlorine content of the MSF supplied for sale is at the lower end of the range normally found in bituminous coals.

A2.5.4 Operation of appliances

Fires are normally lit by using either paper and sticks or a proprietary firelighter, normally comprising porous polyethylene block impregnated with kerosene, although one brand also includes peat. To establish the fire, the primary air supply, i.e. for coal the air entering the fire from below and passing through the fire, is set to a maximum. The fire is considered to be well-established when there is a flame break through above the fire bed. Such breakthrough consists of long yellow flames for bituminous coals and wood and short, bluer or clearer flames, for smokeless fuels. Depending on the fuel and appliance, it may take between 15 and 60 minutes to light a fire.

Householders then restrict the primary air supply to reduce the combustion rate and allow the fire to burn through. The heat output from the fires increases as the fire bed and surrounds get hotter, and reach a maximum of output usually when the fire is glowing red-hot on its top. The fire then dies back, to be refuelled as necessary. Usually, the fire is poked at the refuelling stage to break up any large coal lumps or wood pieces and to encourage ash to fall through the grate. Again depending on the type of fuel and appliance, a refuelling period of 1-2 hours for wood) and 3-4 hours for coal and smokeless fuel may be considered typical.

A decreasing proportion of householders, bank their fires by limiting the primary air supply as much as possible to enable the fuel to burn at reduced output so that the fire will stay alight for a long period, e.g. whilst at work or overnight, without any attendance.

Thus, in the normal operation of a fire, there is an ignition phase, a number of cyclic phases between each refuelling, followed perhaps by banking and recovery phases. In all of these phases, conditions in the fire, on the surface of the fire bed and in the chimney are changing in terms of temperature and gas composition.

Whilst the fire bed, once established, should be red hot at ~800°C, the temperature of the top surface of the fire will vary from a similarly high temperature to as low as ambient for a freshly refuelled fire. Indeed the fresh fuel on the fire only gradually heats up and catches fire. It evolves moisture and then various tars and vapours before eventually they catch fire. Thus there is a period after refuelling and during banking when the fuel effectively gasifies or distils, producing a mix of chemicals at relatively low temperature.

Figure A2.1 provides a simplified illustration of the different stages of the combustion cycle between each refuelling.
As a general guide, householders tend to refuel coal-based fires when the fuel bed has lost about 70% of its original weight whereas those burning wood recharge their fire much later when there may be only be 10% of the original fire bed weight remaining. Replenishing of a wood fire when only a few hot embers remain results in a longer time when the newly fuelled wood is at a relatively low temperature than would otherwise be expected.

As fossil solid fuels burn on a grate, material falls through the grate into the ash pan. This material is mainly ash but also contains unburned fuel, which may glow hot and burn for a while before extinguishing. The material falls through naturally as the fire is burning but this is increased by poking the fire, riddling the grate and during refuelling. The carbon in the undergrate ash ranges typically from 2-8% by weight of dry fuel burnt, with the lower end of the range being expected for bituminous coal, anthracite and coke, and the higher end for some briquettes.

As the fire becomes extinguished it never burns completely out and there will also be a proportion of unburned fuel remaining on the fire bed. Whilst temperatures in the critical 200-500°C band will be experienced by this residual carbon material it is likely that the majority of any chlorine will have been released earlier in the combustion cycle. Nevertheless, ash from solid fuel combustion may contain measurable dioxin levels.

Open fires, by their very nature, have unrestricted secondary air. Consequently the flue gas temperatures are lower than for closed appliances. The latter type of appliance also has less secondary air but higher fire box temperatures.

In an open fire the oxygen content of the flue gases in the chimney are probably at least 18% and will approach 21% at certain stages of the fire’s life. For open fires, the flue temperature quickly cools to less than 100°C because of the dilution air-
effect. However it is quite feasible to have a roaring fire when burning wood and/or household coal, with flames going beyond the chimney breast. Under such conditions some parts of the flue will be in the 200-500°C range.

Measurements have been made of oxygen and flue gas temperatures in closed appliances and very different patterns are observed. Figure A2.2 gives typical data for a closed, wood-burning appliance during a 1.5 hour refuelling period.

![Figure A2.2 Typical temperature and gas concentration profiles from a wood-burning stove over a 1.5 hour test period](image)

Similarly, Figure A2.3 gives data for a room heater with boiler fired by a MSF.
Figure A2.3  Typical temperature and gas concentration profiles from roomheater with boiler fired by a MSF during a 3.8h test period

The refuelling period for the appliance fired with MSF was longer than for wood by a factor of almost two. Refuelling intervals for wood are invariably shorter than for other fuels. In most closed appliances a refuelling period of 1.5 hours would be considered normal for wood, whereas a period of 4 hours would be typical for the less reactive MSF. Thus, it is often the case that wood fires have more than double the number of refuelling cycles.

Data are also given in Figures A2.4 and A2.5 for a cooker fired by wood or MSF.
Figure A2.4  Typical temperature and gas concentration profiles from a cooker burning wood over a 1 hour test period
Figures A2.2 – A2.5 show that oxygen contents in the flue gas range from over 15% immediately after refuelling (because the charging door had been opened) but quickly decreases to 5-10%, before increasing again at the end of the cycle as the fire dies back. Flue temperatures (measured about 2 m above the fire bed) typically range from 200-300°C during the cycle, but occasionally much higher maximum temperatures are observed up to 400°C or higher.

In consideration of the above, there are clearly conditions in all types of domestic appliances of reduced oxygen and temperatures in the 200-500°C range, which could result in dioxin formation. Furthermore, dependent on the appliance and its connection to the flue in domestic situations, it is estimated that the flue gases from closed appliances remain at these temperatures for 5 seconds or so. Again, it is feasible that dioxins will form. However, conditions are never hot enough after any such formation for them to be destroyed.

Airborne dioxins could be produced in any of the following conditions:

- Release from, or formation in, the fire bed as the fuel catches fire and starts to burn. Localised conditions will exist in both open fires and closed appliances for this to occur.

- Gas phase reactions between oxygen and chlorinated VOCs in the combustion gases in the flue. Again there will be occasions in both open fires and closed appliances conducive to dioxin formation but is probable that conditions will persist for longer periods in closed appliances.
Gas-solid reactions in the flue involving entrained carbonaceous particulates and/or deposited soot.

A2.6 Discussion

There is evidence in the literature to associate dioxin concentrations in the low level atmosphere to the domestic burning of coal and wood. Lohmann et al (2000) estimated that 25% of the dioxin levels in winter in two villages in north England were attributed to the households burning coal and wood. This is consistent with studies from Slovakia and Poland (Stenhouse et al, 1998), in which the seasonality of dioxin concentrations indicated a significant contribution from domestic solid fuel combustion.

Combustion of solid fuel is clearly a candidate source of dioxin releases to the atmosphere. Conditions in a range of appliances used in the domestic sector are conducive to dioxin formation. Domestic combustion also results in solids (ash) with measurable dioxin concentrations. What is more uncertain, however, is the overall contribution of domestic solid fuel combustion to the UK inventory of dioxins. Furthermore, the individual contributions from wood and coal-based combustion to the totals released are not known to any level of accuracy, especially under the conditions at which households operate their appliances and use their fuels. In particular, burning of wet fuel and, for wood, this includes unseasoned logs, will prolong the low temperature “stewing” of the fuel on the fire, and likely give rise to higher levels of dioxins.

Also many householders do not operate their appliances under ideal conditions, and real-life combustion conditions are unlikely to be well replicated by the standardised combustion conditions used in laboratory tests. In particular the effects of deposited soot in the chimney are not known with any certainty, but could be significant. Thus data obtained from controlled laboratory experiments, whilst useful, may not give an accurate picture in reflecting the levels of dioxins which are produced from different fuels and appliances.

However, on the basis that fuels of high chlorine content are more likely to yield dioxins, one approach worth consideration would be the imposition of a maximum allowable chlorine content in the “controlled” solid fuels supplied to the domestic sector. In any event, acidic releases from chlorine are undesirable and will attack lower grade steel flues so there is more than one reason for imposing a maximum limit. This would have the merit of being a practicable scheme which could be enforced, in a sector which is hard to control.

A2.7 Recommendation for further research

There is little information available on dioxin emissions from domestic combustion, particularly for fuels “as fired” in domestic situations. For this reason, it is recommended that a series of tests be conducted to determine dioxin emissions from a typical open fire and from a typical closed appliance (taken to represent the bulk of the appliance stock in the domestic sector) when burning either dry or wet fuels, and for wood, freshly felled or properly seasoned, logs.

This information could be used to establish more reliably the relative importance of coal-based fuels and wood to the dioxin inventory and whether their combined contribution to the inventory merits significant effort being made to reduce emissions from these sources.