

# Appendices

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## CONTENTS

|            |  |
|------------|--|
| Appendix 1 | The UK Greenhouse Gas Inventory and the Emission Source Classification |
| Appendix 2 | Energy   |
| Appendix 3 | Energy (Fugitives)   |
| Appendix 4 | Industrial Processes and Solvent                                       |
| Appendix 5 | Agriculture  |
| Appendix 6 | Land Use Change and Forestry   |
| Appendix 7 | Waste  |
| Appendix 8 | Uncertainties  |
| Appendix 9 | Quality Assurance and Quality Control                                  |

# Appendix 1

# The UK Greenhouse Gas Inventory and the Emission Source Classification

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## CONTENTS

|   |   |    |
|---|---|----|
| 1 | INTRODUCTION                                | 1  |
| 2 | FUELS                                       | 2  |
| 3 | NAEI SOURCE CATEGORIES AND IPCC EQUIVALENTS | 5  |
| 4 | REFERENCES                                  | 12 |

# 1 Introduction

The UK Greenhouse Gas Inventory (GHGI) is compiled to fulfil the UK's reporting obligations to UNFCCC. It complies with the IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories (IPCC, 1997a, b, c) and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). The GHGI is based on the same data sets as the National Atmospheric Emissions Inventory (NAEI) which is reported according to the UNECE/CORINAIR format. Hence, the methodology used for the GHGI is consistent with that of the NAEI except for certain sources and reporting conventions which are specific to IPCC. These are discussed in detail in subsequent appendices. The pollutants reported are:

## Direct Greenhouse Gases

- Carbon dioxide
- Methane
- Nitrous Oxide
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur Hexafluoride (SF<sub>6</sub>)

## Indirect Greenhouse Gases

- Nitrogen Oxides (as NO<sub>2</sub>)
- Carbon Monoxide
- Non-Methane Volatile Organic Compounds (NMVOC)
- Sulphur Dioxide

These pollutants are estimated using methodologies corresponding mostly to the detailed sectoral Tier 2/3 methods in the IPCC Guidelines.

The inventories for 1990-1999 were submitted to FCCC in the Common Reporting Format (CRF). This is in accordance with a decision of the Conference of the Parties to the FCCC (FCCC/CP/1999/7). The CRF reports much more detail than the IPCC Sectoral Tables, in that it contains additional tables of activity data as well as updated versions of the IPCC Sectoral Tables. It should be noted that carbon dioxide is reported as net emissions (=emissions – removals) in the CRF whilst in the main part of this report, emissions and removals are reported separately. This means that the totals reported for CO<sub>2</sub> and total greenhouse gas emissions weighted by global warming potential are reported on a different basis between the CRF and the main report. A copy of the CRF accompanies this report on a CD ROM.

Most sources are reported in the detail required by the CRF. The main exceptions are the emissions of individual halocarbon species, which cannot be reported individually because some of these are considered commercially sensitive data within the industries involved. Consequently, emissions data have been aggregated to protect this information. It is however possible to report the total global warming potential of these gases and hence the total global warming potential of all UK greenhouse gases. Also the background tables for Land Use Change and Forestry are not completed because the UK model used differs significantly from the IPCC default methodology.

The UK Inventory uses a 'bottom up' approach based on the combustion of fuels in different economic sectors and estimates of non-combustion emissions from other known sectors to produce detailed sectoral inventories of the 10 pollutants. In addition, estimates are also provided of carbon dioxide emissions using the IPCC Reference Approach. This is a 'top down' inventory calculated from national statistics on production, imports, exports and stock changes of crude oil, natural gas and solid fuels. It is based on a different set of statistics and methodology and produces estimates around 2-5% higher than the 'bottom-up' approach. It is discussed further in Appendix 2.

## 2 Fuels

The fuels data are taken from the Digest of UK Energy Statistics (DUKES), (DTI, 2000) so the fuel definitions and the choice of base source categories in the NAEI reflect those in DUKES. The choice of non-combustion sources generally reflects the availability of data on emissions from these sources.

IPCC Guidelines (IPCC, 1997a) give a list of fuels that should be considered when reporting emissions. Table 1 lists the fuels that are used in the GHGI and indicates how they relate to the fuels reported in the NAEI. In most cases the mapping is fairly obvious but there are a few cases where some explanation is required.

- (i) Aviation Fuels. UK energy statistics report consumption of aviation turbine fuel and this is mapped onto jet gasoline in the GHGI. However aviation turbine fuel includes fuel that is correctly described as jet kerosene using IPCC terminology. For non- CO<sub>2</sub> gases, emissions are estimated from data on numbers of landing-takeoff cycles, so jet kerosene and aviation gasoline emissions are combined.
- (ii) Coal. The IPCC Guidelines (IPCC, 1997a) classify coal as anthracite, coking coal, other bituminous coal and sub-bituminous coal. In mapping the UK fuel statistics to these categories it is assumed that only the coal used in coke ovens is coking coal; and the rest is reported as coal. Most of the coal used in the UK is bituminous coal; anthracite is reported separately.
- (iii) Coke Oven Coke. Gas works coke is no longer manufactured in the UK so all coke and coke breeze consumption is reported as coke oven coke.
- (iv) Colliery Methane. The IPCC Guidelines do not refer to colliery methane but significant use is made of it as a fuel in the UK so emissions are included in the GHGI.
- (v) Orimulsion. Orimulsion® is an emulsion of bitumen and water and was burnt in some power stations in the UK, however its use has now been discontinued
- (vi) Slurry. This is a slurry of coal and water used in some power stations.
- (vii) Sour Gas. Unrefined natural gas is used as a fuel on offshore platforms and in some power stations. It has a higher carbon and sulphur content than mains gas.
- (viii) Wastes used as fuel. The following wastes are used for power generation: municipal solid waste, scrap tyres, poultry litter, landfill gas and sewage gas. Some waste oils and scrap tyres are burnt in cement kilns.

Table 1 Mapping of fuels used in the GHGI and the NAEI

|             | GHGI   | NAEI   |
|-------------|--|--|
| Category    | Subcategory  | Subcategory  |
| Liquid      | Motor Gasoline<br>Aviation Gasoline<br>Jet Gasoline<br>Other Kerosene<br>Gas/Diesel Oil<br>Residual Fuel Oil<br>Orimulsion<br>Liquefied Petroleum Gas<br>Naphtha<br>Petroleum Coke<br>Refinery Gas<br>Other Oil: Other<br>Other Oil: Other<br>Lubricants | Petrol<br>Aviation Spirit<br>Aviation Turbine Fuel <sup>1</sup> (ATF)<br>Burning Oil<br>Gas Oil/ DERV<br>Fuel Oil<br>Orimulsion<br>Liquefied Petroleum Gas (LPG)<br>Naphtha<br>Petroleum Coke<br>Other Petroleum Gas (OPG)<br>Refinery Miscellaneous<br>Waste Oils<br>Lubricants |
| Solid       | Anthracite<br>Coking Coal<br>Coal<br>Coal<br>Coke Oven Coke<br>Patent Fuel<br>Coke Oven Gas<br>Blast Furnace Gas   | Anthracite<br>Coal <sup>2</sup><br>Coal<br>Slurry <sup>3</sup><br>Coke<br>Solid Smokeless Fuel (SSF)<br>Coke Oven Gas<br>Blast Furnace Gas   |
| Gas         | Natural Gas<br>Natural Gas<br>Colliery Methane <sup>5</sup>  | Natural Gas<br>Sour Gas <sup>4</sup><br>Colliery Methane   |
| Other Fuels | Municipal Solid Waste<br>Industrial Waste: Scrap Tyres   | Municipal Solid Waste<br>Scrap Tyres   |
| Biomass     | Wood/Wood Waste<br>Other Solid Biomass: Straw<br>Other Solid Biomass: Poultry Litter<br>Landfill Gas<br>Sludge Gas   | Wood<br>Straw<br>Poultry Litter<br><br>Landfill Gas<br>Sewage Gas  |

1 Includes fuel that is correctly termed jet kerosene.

2 Used in coke ovens.

3 Coal-water slurry used in some power stations

4 Unrefined natural gas used on offshore platforms and some power stations

5 Not referred to in IPCC Guidelines (IPCC, 1997a) but included in GHGI.

### 3 NAEI Source Categories and IPCC Equivalents

Tables 2 to 8 relate the IPCC source categories to the equivalent NAEI base categories. In most cases it is possible to obtain a precise mapping of an NAEI source category to a specific IPCC source category. In some cases the relevant NAEI source category does not correspond exactly to the IPCC source category and in a few cases an equivalent NAEI source category is not estimated or is defined quite differently. As a result, total annual emissions given in the NAEI and GHGI may differ slightly. The source categories responsible for the differences between the GHGI and the NAEI are:

- 1A3a Civil Aviation
- 5 Land Use Change and Forestry
- Forests (NMVOC emission only reported in the NAEI)

Tables 2 to 8 refer to NAEI base categories. Normally the NAEI is not reported in such a detailed form but in the summary UNECE/CORINAIR SNAP97, eleven-sector format.

Table 2: Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Table 1A

| IPCC Source Category  | NAEI Source Category  |
|---|---|
| 1A1a Public Electricity and Heat Production   | Power Stations  |
| 1A1b Petroleum Refining   | Refineries (Combustion)   |
| 1A1ci Manufacture of Solid Fuels  | SSF Production<br>Coke Production   |
| 1A1cii Other Energy Industries  | Collieries<br>Gas Production<br>Gas Separation Plant (Combustion)<br>Offshore Own Gas Use<br>Production of Nuclear Fuel<br>Town Gas Production                  |
| 1A2a Iron and Steel   | Iron and Steel (Combustion)<br>Iron and Steel (Sinter Plant)<br>Iron and Steel (Blast Furnaces)   |
| 1A2b Non-Ferrous Metals<br>1A2c Chemicals<br>1A2d Pulp, Paper and Print<br>1A2e Food Processing, Beverages, Tobacco | Included under Other Industry<br>(Combustion)   |
| 1A2fi Other   | Other Industry (Combustion)<br>Cement (Fuel Combustion)<br>Cement (Non-decarbonizing)<br>Lime Production (Combustion)<br>Autogenerators<br>Ammonia (Combustion) |
| 1A2fii Other (Off-road Vehicles and Other Machinery)  | Other Industry Off-road   |
| 1A3a Civil Aviation   | No comparable category  |
| 1A3b Road Transportation  | Road Transport  |
| 1A3c Railways   | Railways (Freight)<br>Railways (Intercity)<br>Railways (Regional)   |
| 1A3di International Marine  | International Marine  |
| 1A3dii Internal Navigation  | Coastal Shipping  |
| 1A3e Other Transport  | Aircraft Support  |
| 1A4a Commercial/Institutional   | Miscellaneous<br>Public Services<br>Railways (Stationary Sources)   |
| 1A4bi Residential   | Domestic  |
| 1A4bii Residential Off-road   | Domestic, House & Garden  |
| 1A4ci Agriculture/Forestry/Fishing (Stationary)   | Agriculture   |
| 1A4cii Agriculture/Forestry/Fishing (Off-road Vehicles and Other Machinery)   | Agriculture Power Units   |
| 1A4ciii Agriculture/Forestry/Fishing (Fishing)  | Fishing   |
| 1A5a Other: Stationary  | No comparable category-included in 1A4a   |
| 1A5b Other: mobile  | Aircraft Military<br>Shipping Naval   |



Table 3: Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Table 1B

| IPCC Source Category                            | NAEI Source Category   |
|---|--|
| 1B1 a Coal Mining i Mining activities           | Deep-Mined Coal  |
| 1B1 a Coal Mining ii Post mining activities     | Coal Storage & Transport   |
| 1B1 a Coal Mining ii Surface Mines              | Open-Cast Coal   |
| 1B1 b Solid Fuel Transformation                 | Coke Production (Fugitive)<br>SSF Production (Fugitive)<br>Flaring (Coke Oven Gas)   |
| 1B1 c Other                                     | Not Estimated  |
| 1B2 a Oil i Exploration                         | Offshore Oil and Gas (Well Testing)  |
| 1B2 a Oil ii Production                         | Offshore Oil and Gas   |
| 1B2 a Oil iii Transport                         | Offshore Loading<br>Onshore Loading  |
| 1B2 a Oil iv Refining/Storage                   | Refineries (drainage)<br>Refineries (tankage)<br>Refineries (Process)<br>Oil Terminal Storage<br>Petroleum Processes   |
| 1B2 a Oil vi Other                              | Not Estimated  |
| 1B2 a Oil v Distribution of oil products        | Petrol Stations (Petrol Delivery)<br>Petrol Stations (Vehicle Refueling)<br>Petrol Stations (Storage Tanks)<br>Petrol Stations (Spillages)<br>Petrol Terminals (Storage )<br>Petrol Terminals (Tanker Loading)<br>Refineries (Road/Rail Loading) |
| 1B2 b i Natural Gas Production                  | Gasification Processes   |
| 1B2 b ii Natural Gas. Transmission/Distribution | Gas Leakage  |
| 1B2 ciii Venting: Combined                      | Offshore Oil and Gas (Venting)   |
| 1B2 ciii Flaring: Combined                      | Offshore Flaring<br>Refineries (Flares)  |

Table 4: Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Tables 2

| IPCC Source Category                              | NAEI Source Category  |
|---|---|
| 2A1 Cement Production                             | Cement (Decarbonizing)  |
| 2A2 Lime Production                               | Lime Production (Decarbonizing)   |
| 2A3 Limestone and Dolomite Use                    | Glass Production: Limestone and Dolomite<br>Iron and Steel (Blast Furnace): Limestone and Dolomite  |
| 2A4 Soda Ash Production and Use                   | Glass Production : Soda Ash   |
| 2A5 Asphalt Roofing                               | Not Estimated   |
| 2A6 Road Paving with Asphalt                      | Road Construction   |
| 2A7 Other   |   |
| 2B1 Ammonia Production                            | Ammonia Feedstock   |
| 2B2 Nitric Acid Production                        | Nitric Acid Production  |
| 2B3 Adipic Acid Production                        | Adipic Acid Production  |
| 2B4 Carbide Production                            |   |
| 2B5 Other   | Sulphuric Acid Production<br>Chemical Industry (Organic Chemicals)<br>Chemical Industry (Pigment Manufacture)<br>Ship purging   |
| 2C1 Iron and Steel                                | Iron and Steel (non-combustion)<br>Iron and Steel (Electric Arc Furnace)<br>Iron and Steel Flaring (Blast Furnace Gas)<br>Rolling Mills (Hot & Cold Rolling)  |
| 2C2 Ferroalloys Productions                       | No Comparable Source Category   |
| 2C3 Aluminium Production                          | Non-Ferrous Metals (Aluminium Production)   |
| 2C4 SF6 Used in Aluminium and Magnesium Foundries | SF6 Cover Gas   |
| 2C5 Other   | Non-Ferrous Metals (2ndry Copper)<br>Non-Ferrous Metals (2ndry Lead)  |
| 2D1 Pulp and Paper                                | Not Estimated   |
| 2D2 Food and Drink                                | Brewing (barley malting, fermentation, wort boiling)<br>Bread Baking<br>Cider Manufacture<br>Other Food (animal feed;cakes, biscuits, cereals; coffee, margarine and other solid fats; meat ,fish and poultry; sugar)<br>Spirit Manufacture (barley malting, casking, distillation, fermentation, maturation, spent grain drying)<br>Wine Manufacture |
| 2E1 Halocarbon & SF6 By-Product Emissions         | Halocarbons Production (By-Product and Fugitive)  |
| 2E2 Halocarbon & SF6 Fugitive Emissions           |   |
| 2E3 Halocarbon & SF6 Other                        | Not Estimated   |
| 2F1 Refrigeration & Air Conditioning              | Refrigeration<br>Supermarket Refrigeration<br>Mobile Air Conditioning   |
| 2F2 Foam Blowing                                  | Foams   |
| 2F3 Fire Extinguishers                            | Fire Fighting   |
| 2F2 Aerosols                                      | Metered Dose Inhalers<br>Aerosols(Halocarbons)  |
| 2F2 Solvents                                      | Not Occurring   |
| 2F2 Other   | Electronics<br>Training Shoes<br>Electrical Insulation  |

Table 5: Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Table 3

| IPCC Source Category                           | NAEI Source Category  |
|--|---|
| 3A Paint Application                           | Decorative paint (retail decorative)<br>Decorative paint (trade decorative)<br>Industrial Coatings (automotive)<br>Industrial Coatings (agriculture & construction)<br>Industrial Coatings (aircraft)<br>Industrial Coatings (Drum)<br>Industrial Coatings (coil coating)<br>Industrial Coatings (commercial vehicles)<br>Industrial Coatings (high performance)<br>Industrial Coatings (marine)<br>Industrial Coatings (metal and plastic)<br>Industrial Coatings (metal packaging)<br>Industrial Coatings (vehicle refinishing)<br>Industrial Coatings (wood) |
| 3B Degreasing & Dry Cleaning                   | Dry Cleaning<br>Surface Cleaning<br>Leather Degreasing  |
| 3C Chemical Products, Manufacture & Processing | Coating Manufacture (paint)<br>Coating Manufacture (ink)<br>Coating Manufacture (glue)<br>Film Coating<br>Leather coating<br>Other Rubber Products<br>Tyre Manufacture<br>Textile Coating   |
| 3D Other                                       | Aerosols (Car care, Cosmetics & toiletries, household products)<br>Agrochemicals Use<br>Industrial Adhesives<br>Paper Coating<br>Printing<br>Other Solvent Use<br>Non Aerosol Products (household, automotive, cosmetics & toiletries, adhesives and sealants, paint thinner or remover)<br>Seed Oil Extraction<br>Wood Impregnation  |

Table 6: Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Tables 4

| IPCC Source Category   | NAEI Source Category                                      |
|--|---|
| 4A1 Enteric Fermentation: Cattle   | Dairy Cattle Enteric<br>Other Cattle Enteric              |
| 4A2 Enteric Fermentation: Buffalo  | Not Occurring   |
| 4A3 Enteric Fermentation: Sheep  | Sheep Enteric   |
| 4A4 Enteric Fermentation: Goats  | Goats Enteric   |
| 4A5 Enteric Fermentation: Camels & Llamas  | Not Occurring   |
| 4A6 Enteric Fermentation: Horses   | Horses Enteric  |
| 4A7 Enteric Fermentation: Mules & Asses  | Not Occurring   |
| 4A8 Enteric Fermentation: Swine  | Pigs Enteric  |
| 4A9 Enteric Fermentation: Poultry  | Not Occurring   |
| 4A10 Enteric Fermentation : Other: Deer  | Deer Enteric  |
| 4B1 Manure Management: Cattle  | Dairy Cattle Wastes<br>Other Cattle Wastes                |
| 4B2 Manure Management: Buffalo   | Not Occurring   |
| 4B3 Manure Management: Sheep   | Sheep Wastes  |
| 4B4 Manure Management: Goats   | Goats Wastes  |
| 4B5 Manure Management: Camels & Llamas   | Not Occurring   |
| 4B6 Manure Management: Horses  | Horses Wastes   |
| 4B7 Manure Management: Mules & Asses   | Not Occurring   |
| 4B8 Manure Management: Swine   | Pigs Wastes   |
| 4B9 Manure Management: Poultry   | Broilers Wastes<br>Laying Hens Wastes<br>Other Poultry    |
| 4B9a Manure Management: Other: Deer  | Deer Wastes   |
| 4B10 Anaerobic Lagoons   | Not Occurring   |
| 4B11 Liquid Systems  | Manure Liquid Systems                                     |
| 4B12 Solid Storage and Dry Lot   | Manure Solid Storage and Dry Lot                          |
| 4B13 Other   | Manure Other  |
| 4C Rice Cultivation  | Not Occurring   |
| 4D 1 Agricultural Soils: Direct Soil Emissions<br>4D 2 Agricultural Soils: Animal Emissions<br>4D 4 Agricultural Soils: Indirect Emissions | Agricultural Soils Fertiliser<br>Agricultural Soils Crops |
| 4E Prescribed Burning of Savannas  | Not Occurring   |
| 4F1 Field Burning of Agricultural Residues:<br>Cereals   | Barley Residue<br>Wheat Residue<br>Oats Residue           |
| 4F5 Field Burning of Agricultural Residues:<br>Other: Linseed  | Linseed Residue   |
| 4G Other   | Not Estimated   |

Table 7 Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Table 5

| IPCC Source Category <sup>1</sup>                   | NAEI Source Category  |
|---|---|
| 5A Changes in Forest and Other Woody Biomass Stocks | Not estimated   |
| 5B Forest and Grassland Conversion                  | Not estimated   |
| 5C Abandonment of Managed Lands                     | Not estimated   |
| 5D CO <sub>2</sub> Emissions and Removals from Soil | Agricultural Soils: Limestone<br>Agricultural Soils: Dolomite |
| 5E Other  | Not estimated   |

<sup>1</sup> Categories 5A, 5B, 5C and 5E are not included in the NAEI because a time series back to 1970 is unavailable. They are included in the Green House Gas Inventory.

Table 8: Mapping of IPCC Source Categories to NAEI Source Categories:  
IPCC Tables 6&7

| IPCC Source Category   | NAEI Source Category  |
|--|---|
| 6A1 Managed Waste Disposal on Land   | Landfill  |
| 6A2 Unmanaged Waste Disposal on Land   | Not Occurring   |
| 6A3 Other  | Not Occurring   |
| 6B1 Industrial Wastewater<br>6B2 Domestic and Commercial Wastewater<br>6B3 Other | Sewage Sludge Disposal  |
| 6C Waste Incineration  | Incineration: MSW<br>Incineration: Sewage Sludge<br>Incineration: Cremation |
| 6D Other Waste   | Not estimated   |
| 7 Other  | Not estimated   |

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# Appendix 2

## Energy

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### CONTENTS

|   |   |    |
|---|---|----|
| 1 | INTRODUCTION  | 3  |
| 2 | BASIC COMBUSTION MODULE                                 | 3  |
| 3 | CONVERSION OF ENERGY ACTIVITY DATA AND EMISSION FACTORS | 12 |
| 4 | ENERGY AND TRANSFORMATION INDUSTRIES                    | 13 |
|   | 4.1 Electricity Generation                              | 13 |
|   | 4.2 Petroleum Refining                                  | 15 |
|   | 4.3 Manufacture of Solid Fuels                          | 15 |
|   | 4.4 Other Energy Industries                             | 16 |
|   | 4.5 Stored Carbon                                       | 17 |
| 5 | TRANSPORT   | 17 |
|   | 5.1 Aviation  | 17 |
|   | 5.2 Railways  | 19 |
|   | 5.3 Road Transport                                      | 20 |
|   | 5.3.1 Improvements to the 1999 inventory                | 20 |
|   | 5.3.2 Fuel-based emissions                              | 20 |
|   | 5.3.3 Traffic-based emissions                           | 21 |
|   | 5.4 Navigation  | 39 |

---

|     |   |    |
|-----|---|----|
| 5.5 | Other Sectors Combustion  | 39 |
| 5.6 | Other Combustion  | 39 |
| 5.7 | Other Off-Road Sources  | 40 |
| 6   | THE IPCC REFERENCE APPROACH   | 42 |
| 6.1 | Introduction  | 42 |
| 6.2 | Activity Data   | 43 |
| 6.3 | Emission Factors  | 43 |
| 6.4 | Carbon Stored in Products   | 43 |
| 6.5 | Discrepancies between the IPCC Reference and 'Bottom-up'<br>Inventories | 43 |
| 7   | REFERENCES  | 45 |



# 1 Introduction

The previous appendix defined the fuels and source categories used in the NAEI and the GHGI. The aim of this section is to describe in detail the methodology used to estimate the emissions arising from fuel combustion for energy. These sources correspond to IPCC Tables 1A.

There is little continuous monitoring of emissions performed in the UK; hence information is rarely available on actual emissions over a specific period of time from an individual emission source. Clearly it would be impractical to measure every emission source in the UK; therefore, the majority of emissions are estimated from other information such as fuel consumption, distance travelled or some other statistical data related to the emissions. Estimates for a particular source sector are calculated by applying an emission factor to an appropriate statistic. That is:

$$\text{Total Emission} = \text{Emission Factor} \times \text{Activity Statistic}$$

Emission factors are typically derived from measurements on a number of representative sources and the resulting factor applied to the UK environment.

For certain sectors, emissions data are available for individual sites from databases such as the Environment Agency's Pollution Inventory (PI). Hence the emission for a particular sector can be calculated as the sum of the emissions from these point sources. That is:

$$\text{Emission} = \Sigma \text{ Point Source Emissions}$$

However it is necessary to make an estimate of the fuel consumption associated with these point sources, so that the emissions from non-point sources can be estimated from fuel consumption data without double counting. In general the point source approach is only applied to emissions of indirect greenhouse gases for well defined point sources (eg. power stations, cement kilns, refineries). Direct greenhouse gas emissions and most non-industrial sources are estimated using emission factors.

## 2 Basic Combustion Module

For the pollutants and sources discussed in this section the emission results from the combustion of fuel. The activity statistics used to calculate the emission are fuel consumption statistics taken from DTI, (2000). A file of the fuel combustion data used in the inventory is provided on a CD ROM attached to this report. Emissions are calculated according to the equation:

$$E(p,s,f) = A(s,f) \times e(p,s,f)$$

where

$$\begin{aligned} E(p,s,f) &= \text{Emission of pollutant } p \text{ from source } s \text{ from fuel } f && \text{(kg)} \\ A(s,f) &= \text{Consumption of fuel } f \text{ by source } s && \text{(kg or therm)} \\ e(p,s,f) &= \text{Emission factor of pollutant } p \text{ from source } s \text{ from fuel } f \end{aligned}$$

(kg/kg or kg/therm)

The pollutants estimated in this way are:

- carbon dioxide as carbon
- NO<sub>x</sub> as nitrogen dioxide
- nitrous oxide
- methane
- NMVOC
- carbon monoxide
- sulphur dioxide

The sources covered by this module are:

- Domestic
- Miscellaneous
- Public Service
- Refineries (Combustion)
- Iron & Steel (Combustion)
- Iron & Steel (Blast Furnaces)
- Iron & Steel (Sinter Plant)
- Other Industry (Combustion)
- Autogenerators
- Gas Production
- Collieries
- Production of Nuclear Fuel
- Coastal Shipping
- Fishing
- Agriculture
- Ammonia (Combustion)
- Railways (Stationary Sources)
- Aircraft Military
- Shipping Naval

The fuels covered are listed in Appendix 1, though not all fuels occur in all sources.

Tables 1 to 4 list the emission factors used in this module. Emission factors are expressed in terms of kg pollutant/ t for solid and liquid fuels and g/therm for gases. This differs from the IPCC approach which expresses emission factors as t pollutant/ TJ based on the *net calorific value* of the fuel. For gases the NAEI factors are based on the *gross calorific value* of the fuel. This approach is used because the gas consumption data in DTI (2000) are reported in terms of energy content on a gross basis.

The carbon factors used are based on UK sources and should be appropriate for the UK. Emissions factors for solid and liquid fuels are in terms of mass. These should apply for all years provided there is no change in the carbon content of fuel over time. A comparison of the current factors was carried out based on limited industry and supplier data which suggested little variation in liquid fuels. The position regarding coal is under review and more data will be

sought. The comparison suggested that the factor used for LPG was anomalously high. The industry was using factors for propane and butane, the major constituents of LPG. Based on a review of these factors and those suggested by IPCC (1997), a new factor was estimated based on an assumed 80%/20% mixture of propane and butane. This is broadly the proportion of the two gases produced.

DTI (2000) publishes mass and energy balances of fuels used in the UK. These balances compare total supply based on production, exports, imports, stock changes and known losses with the total demand. The difference between total supply and demand is reported as the 'statistical difference'.

Carbon dioxide emissions from biomass combustion are not included in the National Total as suggested in the IPCC Guidelines but emissions of other pollutants are. The NAEI includes emissions from the combustion of wood in the industrial and domestic sectors as well as the combustion of straw in agriculture. DTI (2000) reports estimates of wood and straw combustion for energy use and the estimate of emissions is based on these data. Emission factors are given in Table 4. Emissions from biogas and poultry litter combustion are included in the GHGI and are discussed in Section 4.1 since they occur mainly in electricity generation.

The inventory reports emissions from the combustion of lubricants based on the assumption that 40% of lubricants sold in the UK are eventually burnt as fuel (DTI, 2000). Data collected from waste oil recyclers was inconclusive. These companies produce a good quality recycled oil which is marketed or sold back to the originator. This oil is only a proportion of the total waste oil burnt, much of which is burnt in small waste oil burners in the commercial and construction sectors.

For most of the combustion source categories, the emission is estimated from fuel consumption data reported in the Digests of UK Energy Statistics (DUKES) DTI (2000) and an emission factor appropriate to the type of combustion e.g. commercial gas fired boiler. However the DUKES category 'Other Industries' covers a range of sources and types, so the Inventory disaggregates this category into a number of sub-categories, namely:

- Other Industry
- Other Industry Off-road:- See Section 5.7
- Ammonia Feedstock (natural gas only):- See Appendix 4
- Ammonia (Combustion) (natural gas only):- See Appendix 4
- Cement (Combustion) :- See Appendix 4
- Lime Production (non-decarbonizing) : See Appendix 4

Thus the NAEI category Other Industry refers to stationary combustion in boilers and heaters. The other categories are estimated by more complex methods discussed in the sections indicated. For certain industrial processes (eg. Lime production, cement production and ammonia production), the methodology is discussed in Appendix 4 Industrial Processes as the estimation of the fuel consumption is closely related to the details of the process. However, for these processes, where emissions arise from fuel combustion for energy production, these are *reported* under IPCC Table 1A. The fuel consumption of Other Industry is estimated so that the total fuel consumption of these sources is consistent with DUKES (DTI, 2000).

According to IPCC 1996 Revised Guidelines, electricity generation by companies primarily for their own use is autogeneration, and the emissions produced should be reported under the industry concerned. However, most National Energy Statistics (including the UK) report emissions from electricity generation as a separate category. The UK inventory attempts to report as far as possible according to the IPCC methodology. This includes reporting autogenerators as 'other industry (combustion) ', however this will include iron and steel autogeneration. Also, for certain sectors, data on fuel deliveries are used in preference to data on fuel consumption because deliveries will include autogeneration whereas consumption does not.

Table 1: Emission Factors for the Combustion of Liquid Fuels (kg/t)

| Fuel           | Source   | C                | CH <sub>4</sub>     | N <sub>2</sub> O    | NO <sub>x</sub>   | CO                | NM VOC              | SO <sub>2</sub>   |
|----------------|--|------------------|---------------------|---------------------|-------------------|-------------------|---------------------|-------------------|
| ATF            | Aircraft Military  | 859 <sup>a</sup> | 0.106 <sup>ad</sup> | 0.1 <sup>g</sup>    | 8.5 <sup>ad</sup> | 8.2 <sup>ad</sup> | 0.994 <sup>ad</sup> | 1.0 <sup>z</sup>  |
| Burning Oil    | Domestic   | 859 <sup>a</sup> | 0.309 <sup>b</sup>  | 0.0265 <sup>g</sup> | 2.21 <sup>b</sup> | 0.16 <sup>f</sup> | 0.133 <sup>b</sup>  | 0.6 <sup>z</sup>  |
| Burning Oil(P) | Domestic   | 859 <sup>a</sup> | 0.309 <sup>b</sup>  | 0.0265 <sup>g</sup> | 2.21 <sup>b</sup> | 0.16 <sup>f</sup> | 0.133 <sup>b</sup>  | <0.1 <sup>z</sup> |
| Burning Oil    | Other Sources  | 859 <sup>a</sup> | 0.0432 <sup>b</sup> | 0.0265 <sup>g</sup> | 2.84 <sup>m</sup> | 0.16 <sup>f</sup> | 0.0865 <sup>b</sup> | 0.6 <sup>z</sup>  |
| Gas Oil        | Agriculture  | 857 <sup>a</sup> | 0.225 <sup>b</sup>  | 0.026 <sup>g</sup>  | 2.84 <sup>m</sup> | 0.71 <sup>f</sup> | 0.128 <sup>k</sup>  | 2.8 <sup>z</sup>  |
| Gas Oil        | Domestic   | 857 <sup>a</sup> | 0.303 <sup>b</sup>  | 0.026 <sup>g</sup>  | 2.16 <sup>b</sup> | 0.24 <sup>i</sup> | 0.13 <sup>b</sup>   | 2.8 <sup>z</sup>  |
| Gas Oil        | Fishing;Coastal Shipping,<br>Naval; International Marine | 857 <sup>a</sup> | 0.288 <sup>c</sup>  | 0.2 <sup>t</sup>    | 57 <sup>t</sup>   | 7.4 <sup>t</sup>  | 2.112 <sup>c</sup>  | 19.4 <sup>h</sup> |
| Gas Oil        | Iron&Steel,Other Industry,<br>Refineries                 | 857 <sup>a</sup> | 0.0432 <sup>b</sup> | 0.026 <sup>g</sup>  | 3.46 <sup>b</sup> | 0.24 <sup>i</sup> | 0.0865 <sup>b</sup> | 2.8 <sup>z</sup>  |
| Gas Oil        | Public Service; Miscellaneous                            | 857 <sup>a</sup> | 0.0432 <sup>b</sup> | 0.026 <sup>g</sup>  | 2.84 <sup>b</sup> | 0.24 <sup>i</sup> | 0.0865 <sup>b</sup> | 2.8 <sup>z</sup>  |
| Fuel Oil       | Agriculture; Public Service,<br>Miscellaneous            | 850 <sup>a</sup> | 0.122 <sup>b</sup>  | 0.0243 <sup>g</sup> | 6.99 <sup>m</sup> | 0.5 <sup>i</sup>  | 0.122 <sup>b</sup>  | 28.5 <sup>z</sup> |
| Fuel Oil       | Fishing;Coastal Shipping,<br>International Marine        | 850 <sup>a</sup> | 0.288 <sup>c</sup>  | 0.2 <sup>t</sup>    | 57 <sup>t</sup>   | 7.4 <sup>t</sup>  | 2.11 <sup>c</sup>   | 56.4 <sup>h</sup> |
| Fuel Oil       | Domestic   | 850 <sup>a</sup> | 0.303 <sup>b</sup>  | 0.0243 <sup>g</sup> | 6.99 <sup>m</sup> | 0.5 <sup>i</sup>  | 0.13 <sup>b</sup>   | 28.5 <sup>z</sup> |
| Fuel Oil       | Iron&Steel,Other Industry,<br>Railways (Stationary)      | 850 <sup>a</sup> | 0.122 <sup>b</sup>  | 0.0243 <sup>g</sup> | 7.54 <sup>l</sup> | 0.5 <sup>i</sup>  | 0.122 <sup>b</sup>  | 28.5 <sup>z</sup> |
| Fuel Oil       | Refineries (Combustion)                                  | 850 <sup>a</sup> | 0.122 <sup>b</sup>  | 0.0243 <sup>g</sup> | 4.03 <sup>z</sup> | 1.42 <sup>z</sup> | 0.122 <sup>b</sup>  | 19.9 <sup>z</sup> |
| Lubricants     | Other Industry   | 804 <sup>g</sup> | 0.0432 <sup>e</sup> | 0.026 <sup>e</sup>  | 3.46 <sup>e</sup> | 0.24 <sup>e</sup> | 0.0865 <sup>e</sup> | 2.8 <sup>e</sup>  |
| Naphtha        | Refineries   | 940 <sup>a</sup> | 0.122 <sup>j</sup>  | 0.0182 <sup>g</sup> | 7.54 <sup>j</sup> | 0.5 <sup>j</sup>  | 0.122 <sup>j</sup>  | 0.2 <sup>af</sup> |
| Miscellaneous  | Refineries   | 800 <sup>a</sup> | 0.122 <sup>j</sup>  | 0.0247 <sup>g</sup> | 7.54 <sup>j</sup> | 0.5 <sup>j</sup>  | 0.122 <sup>j</sup>  | 0.2 <sup>af</sup> |
| Petrol         | Refineries   | 855 <sup>a</sup> | 0.0432 <sup>e</sup> | 0.0179 <sup>g</sup> | 3.46 <sup>e</sup> | 0.24 <sup>e</sup> | 0.0865 <sup>e</sup> | 0.4 <sup>z</sup>  |

Table 2: Emission Factors for Combustion of Coal (kg/t)

|                                  | C                  | CH <sub>4</sub>    | N <sub>2</sub> O    | NO <sub>x</sub>   | CO                | NMVOG             | SO <sub>2</sub>    |
|----------------------------------|--------------------|--------------------|---------------------|-------------------|-------------------|-------------------|--------------------|
| Agriculture                      | 659.6 <sup>n</sup> | 0.011 <sup>o</sup> | 0.155 <sup>w</sup>  | 4.31 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.05 <sup>o</sup> | 17.3 <sup>aa</sup> |
| Collieries                       | 659.6 <sup>n</sup> | 0.011 <sup>o</sup> | 0.061 <sup>w</sup>  | 4.53 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.05 <sup>o</sup> | 20.0 <sup>aa</sup> |
| Domestic                         | 676.8 <sup>n</sup> | 15.7 <sup>o</sup>  | 0.119 <sup>w</sup>  | 1.42 <sup>b</sup> | 45.0 <sup>f</sup> | 14 <sup>o</sup>   | 15.4 <sup>aa</sup> |
| Iron & Steel<br>(Combustion)     | 659.6 <sup>n</sup> | 0.011 <sup>o</sup> | 0.0704 <sup>w</sup> | 4.97 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.05 <sup>o</sup> | 17.3 <sup>aa</sup> |
| Miscellaneous,<br>Public Service | 659.6 <sup>n</sup> | 0.011 <sup>o</sup> | 0.143 <sup>w</sup>  | 3.96 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.05 <sup>o</sup> | 17.3 <sup>aa</sup> |
| Other Industry                   | 659.6 <sup>n</sup> | 0.011 <sup>o</sup> | 0.213 <sup>w</sup>  | 4.65 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.05 <sup>o</sup> | 17.3 <sup>aa</sup> |
| Railways                         | 659.6 <sup>n</sup> | 0.011 <sup>o</sup> | 0.0753 <sup>w</sup> | 5.04 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.05 <sup>o</sup> | 17.3 <sup>aa</sup> |
| Autogenerators                   | 659.6 <sup>n</sup> | 0.02 <sup>o</sup>  | 0.0658 <sup>w</sup> | 4.65 <sup>b</sup> | 4.1 <sup>i</sup>  | 0.03 <sup>o</sup> | 17.3 <sup>aa</sup> |

Table 3 Emission Factors for Combustion of Solid Fuels (kg/t)

|            |   | C                  | CH <sub>4</sub>     | N <sub>2</sub> O    | NO <sub>x</sub>    | CO                | NMVOC               | SO <sub>2</sub>    |
|------------|---|--------------------|---------------------|---------------------|--------------------|-------------------|---------------------|--------------------|
| Anthracite | Domestic                                      | 813.4 <sup>n</sup> | 2 <sup>o</sup>      | 0.14 <sup>w</sup>   | 1.6 <sup>b</sup>   | 45 <sup>f</sup>   | 1.7 <sup>o</sup>    | 14.0 <sup>aa</sup> |
| Coke       | Agriculture                                   | 795.4 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.144 <sup>g</sup>  | 4.0 <sup>b</sup>   | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Coke       | Coke Production;<br>SSF Production            | 820 <sup>n</sup>   | 0.011 <sup>p</sup>  | 0.221 <sup>w</sup>  | 4.8 <sup>b</sup>   | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Coke       | Domestic                                      | 803.6 <sup>n</sup> | 5.8 <sup>p</sup>    | 0.111 <sup>w</sup>  | 1.33 <sup>b</sup>  | 45 <sup>q</sup>   | 4.9 <sup>p</sup>    | 16 <sup>ab</sup>   |
| Coke       | I&S (Sinter Plant)                            | 795.4 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.221 <sup>w</sup>  | 4.13 <sup>b</sup>  | 115 <sup>ae</sup> | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Coke       | I&S (Combustion) Other<br>Industry            | 795.4 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.221 <sup>w</sup>  | 4.8 <sup>b</sup>   | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Coke       | Railways                                      | 795.4 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.144 <sup>g</sup>  | 4.8 <sup>b</sup>   | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Coke       | Miscellaneous; Public Service                 | 795.4 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.144 <sup>g</sup>  | 4.0 <sup>b</sup>   | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Petro-Coke | Refineries                                    | 800 <sup>a</sup>   | 0.0127 <sup>p</sup> | 0.256 <sup>w</sup>  | 6.9 <sup>z</sup>   | 2.57 <sup>z</sup> | 0.0577 <sup>p</sup> | 42.5 <sup>z</sup>  |
| SSF        | Agriculture; Miscellaneous;<br>Public Service | 766.3 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.143 <sup>g</sup>  | 3.96 <sup>b</sup>  | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| SSF        | Domestic                                      | 774.2 <sup>n</sup> | 5.8 <sup>p</sup>    | 0.112 <sup>w</sup>  | 1.32 <sup>b</sup>  | 45 <sup>q</sup>   | 4.9 <sup>p</sup>    | 16 <sup>ab</sup>   |
| SSF        | Other Industry                                | 766.3 <sup>n</sup> | 0.011 <sup>p</sup>  | 0.218 <sup>w</sup>  | 4.75 <sup>b</sup>  | 4.1 <sup>p</sup>  | 0.05 <sup>p</sup>   | 19 <sup>ab</sup>   |
| Straw      | Agriculture                                   | 418 <sup>g</sup>   | 4.28 <sup>g</sup>   | 0.057 <sup>g</sup>  | 1.43 <sup>g</sup>  | 71.3 <sup>g</sup> | 8.56 <sup>g</sup>   | 0                  |
| Wood       | Domestic                                      | 264 <sup>g</sup>   | 3.61 <sup>b</sup>   | 0.0388 <sup>g</sup> | 0.722 <sup>b</sup> | 99.3 <sup>g</sup> | 5.42 <sup>b</sup>   | 0.037 <sup>m</sup> |
| Wood       | Other Industry                                | 470 <sup>g</sup>   | 0.482 <sup>b</sup>  | 0.069 <sup>g</sup>  | 3.21 <sup>b</sup>  | 7.1 <sup>g</sup>  | 0.803 <sup>b</sup>  | 0.037 <sup>m</sup> |

Table 4 Emission Factors for the Combustion of Gaseous Fuels (g/therm)

| Fuel              | Source   | C                  | CH <sub>4</sub>     | N <sub>2</sub> O    | NO <sub>x</sub>   | CO                  | NMVOG               | SO <sub>2</sub>   |
|-------------------|--|--------------------|---------------------|---------------------|-------------------|---------------------|---------------------|-------------------|
| Blast Furnace Gas | Coke Production  | 6273 <sup>n</sup>  | 0.0317 <sup>t</sup> | 0.211 <sup>t</sup>  | 11 <sup>t</sup>   | 15.8 <sup>t</sup>   | 0.317 <sup>t</sup>  | 0                 |
| Blast Furnace Gas | Iron&Steel (Comb.), Blast Furnaces, Iron&Steel (Flaring)                   | 6273 <sup>n</sup>  | 11.8 <sup>t</sup>   | 0.211 <sup>t</sup>  | 8.33 <sup>t</sup> | 4.17 <sup>t</sup>   | 0.591 <sup>t</sup>  | 0                 |
| Coke Oven Gas     | Other Sources  | 1599 <sup>n</sup>  | 0.791 <sup>b+</sup> | NE                  | 8.55 <sup>b</sup> | 6.17 <sup>s</sup>   | 1.85 <sup>b+</sup>  | 53.8 <sup>v</sup> |
| Coke Oven Gas     | Blast Furnaces   | 1599 <sup>n</sup>  | 0.791 <sup>b+</sup> | NE                  | 64 <sup>v</sup>   | 49.2 <sup>t</sup>   | 1.85 <sup>b+</sup>  | 53.8 <sup>v</sup> |
| Coke Oven Gas     | Coke Production  | 1599 <sup>n</sup>  | 0.791 <sup>b+</sup> | NE                  | 51.1 <sup>v</sup> | 49.2 <sup>t</sup>   | 1.85 <sup>b+</sup>  | 53.8 <sup>v</sup> |
| LPG               | Domestic   | 1712 <sup>ag</sup> | 0.0971 <sup>m</sup> | 0.0095 <sup>g</sup> | 4.85 <sup>b</sup> | 0.863 <sup>s</sup>  | 0.194 <sup>m</sup>  | 0                 |
| LPG               | I&S, Other Industry, Refineries, Gas Production                            | 1712 <sup>ag</sup> | 0.0971 <sup>m</sup> | 0.0095 <sup>g</sup> | 9.4 <sup>m</sup>  | 0.25 <sup>s</sup>   | 0.194 <sup>m</sup>  | 0                 |
| Natural Gas       | Agriculture, Miscellaneous, Public Service                                 | 1501 <sup>r</sup>  | 0.38 <sup>b</sup>   | 0.0095 <sup>g</sup> | 4.88 <sup>m</sup> | 0.25 <sup>i</sup>   | 0.38 <sup>b</sup>   | 0                 |
| Natural Gas       | Coke Production, SSF Prodn, Nuclear Fuel Prodn, Refineries, Blast Furnaces | 1501 <sup>r</sup>  | 0.38 <sup>b</sup>   | 0.0095 <sup>g</sup> | 9.5 <sup>b</sup>  | 0.25 <sup>i</sup>   | 0.38 <sup>b</sup>   | 0                 |
| Natural Gas       | Domestic   | 1501 <sup>r</sup>  | 0.285 <sup>b</sup>  | 0.0095 <sup>g</sup> | 4.85 <sup>y</sup> | 0.863 <sup>f</sup>  | 0.665 <sup>b</sup>  | 0                 |
| Natural Gas       | Collieries, Gas Prodn, Iron&Steel, Other Industry, Railways                | 1501 <sup>r</sup>  | 0.38 <sup>b</sup>   | 0.0095 <sup>g</sup> | 9.5 <sup>b</sup>  | 0.25 <sup>i</sup>   | 0.38 <sup>b</sup>   | 0                 |
| Natural Gas       | Autogenerators   | 1501 <sup>r</sup>  | 0.579 <sup>g</sup>  | 0.351 <sup>g</sup>  | 4.69 <sup>u</sup> | 0.019 <sup>ac</sup> | 0.51 <sup>l</sup>   | 0                 |
| Natural Gas       | Ammonia (Comb.)  | 1501 <sup>r</sup>  | 0.38 <sup>b</sup>   | 0.0095 <sup>g</sup> | 19.4 <sup>d</sup> | 0.25 <sup>i</sup>   | 0.38 <sup>b</sup>   | 0                 |
| OPG               | Gas production, Other Industry, Refineries                                 | 1627 <sup>a</sup>  | 0.324 <sup>b+</sup> | NE                  | 13.6 <sup>b</sup> | 0.25 <sup>s</sup>   | 0.647 <sup>b+</sup> | 0                 |
| Colliery Methane  | All Sources  | 1501 <sup>s</sup>  | 0.38 <sup>s</sup>   | 0.0095 <sup>g</sup> | 9.5 <sup>s</sup>  | 0.25 <sup>s</sup>   | 0.38 <sup>s</sup>   | 0                 |
| Sewage Gas        | Public Services  | 2891 <sup>g</sup>  | 64.9 <sup>m</sup>   | 0.0095 <sup>g</sup> | 94.6 <sup>m</sup> | 17.4 <sup>m</sup>   | 4.99 <sup>m</sup>   | 0                 |
| Landfill Gas      | Miscellaneous  | 2891 <sup>g</sup>  | 64.9 <sup>m</sup>   | 0.0095 <sup>g</sup> | 94.6 <sup>m</sup> | 17.4 <sup>m</sup>   | 4.99 <sup>m</sup>   | 0                 |



## Footnotes to Tables 1 to 4

- a UKPIA (1989)
- b CORINAIR (1992)
- b+ Derived from CORINAIR(1992) assuming 30% of total VOC is methane
- c Methane factor estimated as 12% of total hydrocarbon emission factor taken from EMEP/CORINAIR(1996) based on speciation in IPCC (1997c).
- d Based on operators data : Terra Nitrogen(2000), Kemira(2000)
- e As gas oil
- f USEPA (1977)
- g IPCC (1997c)
- h EMEP (1990)
- i Walker *et al* (1985)
- j As fuel oil.
- k NMVOC emission factor estimated as 98.75% of total hydrocarbon emission factor taken from USEPA (1977).
- l USEPA(1997) estimated from total VOC factor and the methane factor given
- m USEPA(1997)
- n British Coal (1989)
- o Brain *et al*, (1994)
- p As coal
- q As anthracite
- r British Gas (1992)
- s As natural gas
- t EMEP/CORINAIR(1996)
- u Powergen (1997), National Power (1997)
- v Emission factor derived from emissions reported in the PI. Environment Agency (2000)
- w Fynes et al (1994)
- x as coke
- y British Gas (1994)
- z UKPIA (2000), Emission factor for 1999 derived from data supplied by UKPIA
- aa Emission factor for 1999 based on data provided by RJB(2000), Scottish Coal(2000), Celtic Energy (2000), Tower (2000), Betwys(2000)
- ab Munday (1990)
- ac Powergen (1994)
- ae Factor derived from British Steel (2000) emissions data.
- ad EMEP/CORINAIR (1999)
- af UKPIA (2000)
- ag LPG factor assumes an 80/20 mixture of propane/butane by weight.

### 3 Conversion of Energy Activity Data and Emission Factors

In the NAEI databases, activity data are stored in Mtonnes for solid and liquid fuels and Mtherms (gross) for gaseous fuels. Emission factors are in consistent units namely: ktonnes/Mtonne for solid and liquid fuels and ktonnes/Mtherm (gross) for gaseous fuels. For some sources emission factors are taken from IPCC and CORINAIR sources and it is necessary to convert them from a net energy basis to a gross energy basis. For solid and liquid fuels:

$$H_n = m h_g f$$

and for gaseous fuels

$$H_n = H_g f$$

where:

|       |  |         |
|-------|--|---------|
| $H_n$ | Equivalent energy consumption on net basis             | (kJ)    |
| $m$   | Fuel consumption                                       | (kg)    |
| $h_g$ | Gross calorific value of fuel                          | (kJ/kg) |
| $f$   | Conversion factor from gross to net energy consumption | (-)     |
| $H_g$ | Energy Consumption on gross basis                      | (kJ)    |

In terms of emission factors:

$$e_m = e_n h_g f$$

or

$$e_g = e_n f$$

where:

|       |                                       |               |
|-------|---------------------------------------|---------------|
| $e_m$ | Emission factor on mass basis         | (kg/kg)       |
| $e_n$ | Emission factor on net energy basis   | (kg/kJ net)   |
| $e_g$ | Emission factor on gross energy basis | (kg/kJ gross) |

The gross calorific values of fuels used in the UK are tabulated in DTI, (2000). The values of the conversion factors used in the calculations are given in Table 5.

Table 5: Conversion Factors for Gross to Net Energy Consumption

| Fuel                   | Conversion Factor |
|------------------------|-------------------|
| Other Gaseous Fuels    | 0.9               |
| Solid and Liquid Fuels | 0.95              |
| LPG and OPG            | 0.92              |
| Blast Furnace Gas      | 1.0               |

The values given for solid, liquid and other gaseous fuels are taken from IPCC Guidelines (IPCC, 1997). The value used for LPG is based on the calorific value for butane, the major

constituent of LPG (Perry, 1973). Blast furnace gas consists mainly of carbon monoxide and carbon dioxide. Since little hydrogen is present, the gross calorific value and the net calorific values will be the same.

## 4 Energy and Transformation Industries

### 4.1 ELECTRICITY GENERATION

The NAEI category Power Stations is mapped onto 1A1 Electricity and Heat Production. In the NAEI, the category Power Stations aims to report as near as possible emissions from electricity generation by companies whose main business is producing electricity (Major Power Producers) and hence excludes autogenerators. The fuel consumption entries from DUKES are chosen to obtain the best match with this definition. The coal and natural gas entries used are very close to this definition but the fuel oil entry does contain a small contribution from transport undertakings and groups of factories.

Table 6: Emission Factors for Power Stations

|                         | Unit    | CO <sub>2</sub> <sup>1</sup> | CH <sub>4</sub>       | N <sub>2</sub> O    | NO <sub>x</sub>    | CO                 | NM VOC              | SO <sub>2</sub>    |
|-------------------------|---------|------------------------------|-----------------------|---------------------|--------------------|--------------------|---------------------|--------------------|
| Coal                    | kg/t    | 588.23 <sup>c</sup>          | 0.02 <sup>s</sup>     | 0.073 <sup>i</sup>  | 6.7 <sup>j</sup>   | 1.03 <sup>j</sup>  | 0.0296 <sup>j</sup> | 18.9 <sup>j</sup>  |
| Fuel Oil                | kg/t    | 850 <sup>a</sup>             | 0.0054 <sup>p</sup>   | 0.0243 <sup>d</sup> | 8.46 <sup>j</sup>  | 1.29 <sup>j</sup>  | 0.028 <sup>j</sup>  | 43.1 <sup>j</sup>  |
| Orimulsion              | kg/t    | 597.5 <sup>e</sup>           | 0.0163 <sup>f</sup>   | 0.017 <sup>f</sup>  | 9.36 <sup>u</sup>  | 1.39 <sup>u</sup>  | 0.0437 <sup>u</sup> | 70.0 <sup>u</sup>  |
| Gas Oil                 | kg/t    | 857 <sup>a</sup>             | 0.0432 <sup>b</sup>   | 0.026 <sup>d</sup>  | 2.75 <sup>j</sup>  | 0.473 <sup>j</sup> | 0.0865 <sup>b</sup> | 3.25 <sup>j</sup>  |
| MSW                     | kg/t    | 75 <sup>l</sup>              | 0.000797 <sup>r</sup> | 0.03 <sup>v</sup>   | 1.371 <sup>t</sup> | 0.197 <sup>t</sup> | 0.0308 <sup>t</sup> | 0.076 <sup>t</sup> |
| Tyres                   | kg/t    | 757 <sup>o</sup>             | 0.912 <sup>q</sup>    | 0.0184 <sup>q</sup> | NE                 | NE                 | NE                  | NE                 |
| Poultry Litter          | kg/t    | NE                           | 0.251 <sup>q</sup>    | 0.0334 <sup>q</sup> | 0.568 <sup>j</sup> | 0.317 <sup>j</sup> | 0.009 <sup>j</sup>  | 0.575 <sup>j</sup> |
| Landfill/<br>Sewage Gas | g/therm | 2891 <sup>q</sup>            | 64.9 <sup>h</sup>     | 0.0095 <sup>q</sup> | 94.6 <sup>h</sup>  | 17.4 <sup>h</sup>  | 4.99 <sup>h</sup>   | 0                  |
| Sour Gas                | g/therm | 1916 <sup>n</sup>            | 0.0228 <sup>m</sup>   | 0.0095 <sup>q</sup> | 21.0 <sup>j</sup>  | 12.0 <sup>m</sup>  | 0.0912 <sup>j</sup> | 7.68 <sup>j</sup>  |
| Natural Gas             | g/therm | 1501 <sup>g</sup>            | 0.579 <sup>d</sup>    | 0.351 <sup>k</sup>  | 2.96 <sup>j</sup>  | 0.907 <sup>j</sup> | 0.581 <sup>j</sup>  | 0.144 <sup>j</sup> |

1 Emission factor as kg carbon/ t unit fuel consumption

a UKPIA (1989)

b CORINAIR (1992)

c British Coal (1989)

d IPCC(1997c)

e BITOR(1995)

f As fuel oil but adjusted on basis of gross calorific value

g British Gas (1992)

h USEPA(1997)

i Fynes et al (1994)

|    |  |
|----|--|
| j  | Based on reported emissions data from PI (EA, 2000), Environment Agency (2000a) and Station Operators.             |
| k  | Stewart (1997)   |
| l  | Royal Commission on Environmental Pollution (1993)   |
| m  | EMEP/CORINAIR (1996)   |
| n  | Stewart et al (1996)   |
| o  | Based on composition data in Ogilvie (1995)  |
| p  | Stewart et al (1996) estimated from total VOC factor assuming 27.2% is methane after USEPA(1997)                   |
| q  | IPCC(1997)   |
| r  | estimated from THC data in CRI (Environment Agency, 1997) assuming 3.% methane split given in EMEP/CORINAIR (1996) |
| s  | Brain (1994)   |
| t  | Environment Agency (2000)  |
| u  | 1997 factor reported in Goodwin et al (1999). Fuel no longer used.   |
| v  | IPCC (2000)  |
| NE | Not Estimated  |

In the NAEI, the Autogenerators category reports emissions from electricity generation by companies primarily for their own consumption. The Inventory makes no distinction between electricity generation and combined heat and power or heat plants. Hence CHP systems where the electricity is fed into the public supply are classified as power stations and CHP systems where the electricity is used by the generator are classified as autogeneration. The Autogenerators category is mapped onto the IPCC category 1A2f Other Industry. The IPCC 1A1 category also refers to CHP plant and heat plant.

However, the Autogenerators category also contains consumption in the Iron & Steel Industry. The emission factors used for Power Stations are shown in Table 6. The NO<sub>x</sub> and SO<sub>2</sub> emissions from coal and oil stations are based on estimates for individual power stations released by the Environment Agency (2000a). The Environment Agency emissions are reported on a power station basis so those from coal fired plant will include emissions from the fuel oil used to light up the boilers. A correction has been applied to the data so that the coal emissions reported in the NAEI pertain only to the coal burnt, and the oil emissions apply only to the oil burnt. This is necessary to fulfil IPCC and UNECE reporting requirements.

From 1991 to 1997 some UK power stations burnt orimulsion, an emulsion of bitumen and water. DTI (1998) gives the UK consumption of orimulsion. This fuel is only used by the electricity supply industry so these data were used in the category Power Stations. The carbon content of the fuel was taken from the manufacturers specification (BITOR, 1995). The emissions of NO<sub>x</sub>, SO<sub>2</sub>, NMVOC and CO were taken from Environment Agency (1999) but emission factors for methane and N<sub>2</sub>O were derived from those of heavy fuel oil but adjusted on the basis of the gross calorific value. The CO emission factor is based on measured data. This fuel is no longer used.

Electricity has been generated from the incineration of municipal solid waste (MSW) for some years now, though generation capacity has recently increased markedly owing to construction and upgrading of incinerators to meet new regulations by the end of 1996. Data have become available (DTI, 2000) on the amount of waste used in electricity generation and the emissions from the incinerators (Environment Agency, 2000). In previous inventories, these emissions were reported as waste disposal, but it is now possible to report the electricity generation component separately under Power Stations. Since 1997, all MSW incinerators have generated electricity so the waste incineration category has reduced to zero. In the 1999 Inventory the

gross calorific value of MSW has been revised (DTI, 2000) resulting in a very small change in emissions.

In addition to MSW combustion, the inventory now reports emissions from the combustion of scrap tyres and poultry litter to generate electricity. The tyre emissions are based on estimates compiled by DTI (2000) and a carbon emission factor based on the carbon content of tyres (Ogilvie, 1995). IPCC default factors based on oil are used. In the case of poultry litter, the carbon emission factor is zero and those for other pollutants are based on Environment Agency (2000) data and IPCC (1997) defaults for biomass. The consumption of poultry litter is based on the operator's estimates of plant capacity.

Emission estimates were made from the generation of electricity from landfill gas and sewage gas (DTI, 2000). It was assumed that the electricity from this source was fed into the public supply or sold into non-waste sectors and hence classified as public power generation. The gases are normally used to power reciprocating gas (or dual-fuel engines) which may be part of combined heat and power schemes. The emission factors used were those of a 2-stroke lean burn reciprocating engine (USEPA, 1997). These engines are normally part of CHP schemes with the heat produced being used locally. DTI (2000) reports the energy for electricity production and for heat production separately. The emissions for electricity generation are categorised under public power whilst those for heat production are reported under miscellaneous for landfill gas and public services for sewage gas.

## 4.2 PETROLEUM REFINING

The NAEI category Refineries is mapped onto the IPCC category 1A1b Petroleum Refining. The emission factors used are shown in Table 1. Included in this category is an emission from the combustion of petroleum coke. This emission arises from the operation of fluidized bed catalytic crackers. During the cracking processes coke is deposited on the catalyst degrading its performance. The catalyst must be continuously regenerated by burning off the coke. The hot flue gases from the regeneration stage are used as a source of heat for the process. Since the combustion provides useful energy and the estimated amount of coke consumed is reported (DTI, 2000), the emissions are reported under 1A1b Petroleum Refining rather than as a fugitive emission under 1B2. Emission factors are either based on operators' data (UKPIA, 2000) or IPCC (1997) defaults for oil. The NAEI definition of refinery aims to include all combustion sources and includes refinery fuels, electricity generation in refineries and fuel oils burnt in the petroleum industry. In previous inventories the consumption of LPG and OPG by 'gas separation plants' was classified under refineries. However, it has become clear that these processes occur in oil terminals, reported under offshore oil and gas (see Appendix 3). However, as OPG and LPG are already reported under offshore own gas use this was a double count and has been removed.

## 4.3 MANUFACTURE OF SOLID FUELS

The mappings used for these categories are given in Appendix 1 and emission factors for energy consumption in these industries are given in Tables 1-4. The fuel consumption for these categories are taken from DTI, (2000). The emissions from these sources where it is clear that the fuel is being burnt for energy production are calculated as in the base combustion module and reported in IPCC Table 1A Energy. However, where the fuel is used as a feedstock resulting in it being transformed into another fuel, which may be burnt elsewhere, a more

complex treatment is needed. The approach used by the NAEI is to perform a carbon balance over coke production, solid smokeless fuel (SSF) production and blast furnaces. This procedure ensures that there is no double counting of carbon and is consistent with IPCC guidelines. No town gas was manufactured in the UK over the period covered by these estimates so this is not considered.

The processes involved are:

*Coke Production*

coal → coke + coke oven gas + carbon emission

*Solid Smokeless Fuel Production*

coal/petro-coke → SSF + carbon emission

Hence by estimating the carbon content of the fuel consumed in these processes and the carbon content of the coke, coke-oven gas and SSF produced, the carbon emission from each process can be calculated. The other transformation process is blast furnaces, which is discussed here because it is included in the carbon balance. The process is:

*I&S Blast Furnaces*

coke → blast furnace gas + carbon sequestered + carbon emission

Again by estimating the carbon content of the coke consumed and the blast furnace gas produced, the carbon emission can be estimated.

In reality the carbon emission is in the form of coke oven gas, coal tars used as fuel and blast furnace gas that is unaccounted for in the energy statistics with a contribution from the uncertainty in the estimates of input and output fuels and their carbon content. The calculations are so arranged that the total carbon emission corresponds to the carbon content of the input fuels in accordance with IPCC Guidelines.

In reporting emissions from these processes, emissions arising from fuel combustion for energy are reported under 1A1ci Manufacture of Solid Fuels whilst emissions arising from the process are reported under 1B1b Solid Fuel Transformation. In the case of blast furnaces, energy emissions are reported under 1A2a Iron and Steel and process emissions under 2C1 Iron and Steel Production. The details of the carbon balances are discussed in the relevant sections in Appendices 3 and 4.

## 4.4 OTHER ENERGY INDUSTRIES

Appendix 1 shows the NAEI source categories mapped onto 1A1cii Other Energy Industries. All these emissions are treated according to the base combustion module using emission factors given in Tables 1 to 4. However, the treatment of gas oil use on offshore installations is anomalous: this is included in the NAEI category Coastal Shipping and hence is mapped to 1A3dii Internal Navigation. There are no 'double counts' in these emissions.

The estimation of emissions from natural gas, LPG and OPG used as a fuel in offshore installations and onshore terminals is discussed in Appendix 3. Although these emissions are reported in category 1A1cii, the methodology used in their estimation is very much linked to the estimation of offshore fugitive emissions.

## 4.5 STORED CARBON

The UK Inventory does not use the IPCC default methodology for stored carbon because it is not clear what processes it represents or if it is applicable to the UK. The procedure adopted, is to report emissions from the combustion of fuels. Emissions, from the non-energy use of fuels are assumed to be zero (ie the carbon is sequestered as products) unless a process emission can be identified. Hence, emissions are estimated from the following processes which involve feedstock use:

- Catalytic Crackers- see Section 4.2
- Ammonia Production - see Appendix 4
- Aluminium Production - see Appendix 4
- Iron & Steel Processes- see Appendix 4
- Lubricant Combustion - see Section 2

# 5 Transport

## 5.1 AVIATION

The NAEI category Air Transport gives an estimate of emissions within a 1000 m ceiling of landing and take-off. The IPCC requires an estimate of emissions from 1A3ai International Aviation and 1A3aii Domestic both including emissions from the cruise phase of the flight as well as the LTO so a method was devised based on the following assumptions and information:

- (i) Total inland deliveries of aviation spirit and aviation turbine fuel to air transport are given in DTI (2000). This is the best approximation of aviation bunker fuel consumption available and is assumed to cover international, domestic and military use.
- (ii) Data on arrivals and departures of domestic aircraft at UK airports are reported by DETR (2000b). This was used to estimate total domestic and international landing and take-offs (LTO).
- (iii) Data on domestic aircraft km are reported by DETR (2000b).
- (iv) Using IPCC default fuel consumption factors for domestic LTOs and cruising together with the LTO data and total domestic km flown, an estimate was made of the total fuel consumption of domestic flights.
- (v) Total consumption by military aviation is given in ONS (1995) and MOD (2000a) and is assumed to be aviation turbine fuel. Emissions from military aircraft are reported under 1A5 Other.

- (vi) An estimate of international fuel consumption was made by deducting military fuel and domestic fuel from the inland deliveries of aviation fuel calculated in (i).

Based on these assumptions the total consumptions of aviation turbine fuel and aviation spirit by domestic and international flights were estimated. Hence, it was a simple matter to calculate the carbon dioxide emission using the emission factors given in IPCC Guidelines (IPCC, 1997) and shown in Table 7. Data on domestic and international aircraft movements taken from DETR (2000b) are shown in Table 8. Domestic flights are those entirely within the UK, Isle of Man and the Channel Isles. International flights are those flown between the UK, Isle of Man and the Channel Isles and points within other countries. This definition differs slightly from the IPCC definition (IPCC, 2000) in that journeys involving departure in the UK, a stop in the UK and then departure for another country would be counted as a domestic movement and an international movement. Under the IPCC definition such a journey would be counted as domestic plus international only if passengers or cargo were dropped at the stop. Otherwise the journey would be an international one. However, the proportion of such journeys will be small.

Table 7: Carbon Dioxide Emission Factors for Aviation (kg/t)

|                       | CO <sub>2</sub> <sup>1</sup> | SO <sub>2</sub>  |
|-----------------------|------------------------------|------------------|
| Aviation Turbine Fuel | 859                          | 1.0 <sup>2</sup> |
| Aviation Spirit       | 865                          | 1.0 <sup>2</sup> |

1 Emission factor as kg carbon/t.

2 UKPIA (1999). Factor for 1998

Table 8: Aircraft Movement Data

|                           | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---------------------------|------|------|------|------|------|------|------|------|------|------|
| Domestic LTOs (000s)      | 301  | 289  | 295  | 302  | 308  | 322  | 333  | 341  | 355  | 365  |
| International LTOs (000s) | 410  | 394  | 429  | 440  | 466  | 484  | 510  | 541  | 581  | 615  |
| Domestic Aircraft Gm      | 92   | 92   | 98   | 101  | 103  | 109  | 114  | 119  | 125  | 127  |

Emissions from international aviation are reported for information only and are not included in national totals.

Emissions from non-CO<sub>2</sub> pollutants were calculated according to the very simple EMEP/CORINAIR/IPCC methodology described in EMEP/CORINAIR (1996) and IPCC(1997c). The procedure was:

1. Data on the annual number of domestic and international landing and takeoff cycles (LTO) (DETR, 2000b) were used together with the default emission factors in Table 9 to estimate the emissions within the take-off and landing phase of the domestic and international flights.
2. The fuel consumptions within the cruise phases of the domestic and international flights were then calculated by subtracting the LTO fuel consumption from the total domestic and international consumptions.



3. The emissions within the cruise phase were calculated using the cruise emission factors in Table 9 together with the cruise fuel consumption.

The current methodology will overestimate emissions from aircraft. This is because only two aircraft types are considered and the default factors used pertain to older models. It is clear, that more smaller modern aircraft are in use on domestic and international routes. Currently the use of a more detailed model for estimating aircraft emissions is under consideration.

Table 9: Non- CO<sub>2</sub> Emission Factors for Aviation

|                      | Units     | CH <sub>4</sub>    | N <sub>2</sub> O | NO <sub>x</sub>   | CO                 | NMVOG              | Fuel |
|----------------------|-----------|--------------------|------------------|-------------------|--------------------|--------------------|------|
| Domestic LTO         | kg/LTO    | 0.394 <sup>a</sup> | 0.1 <sup>b</sup> | 9.0 <sup>a</sup>  | 16.9 <sup>a</sup>  | 3.706 <sup>a</sup> | 1000 |
| International LTO    | kg/LTO    | 6.96 <sup>a</sup>  | 0.2 <sup>b</sup> | 23.6 <sup>a</sup> | 101.3 <sup>a</sup> | 65.54 <sup>a</sup> | 2400 |
| Domestic Cruise      | kg/t fuel | 0 <sup>b</sup>     | 0.1 <sup>b</sup> | 11 <sup>b</sup>   | 7 <sup>b</sup>     | 0.7 <sup>b</sup>   | -    |
| International Cruise | kg/t fuel | 0 <sup>b</sup>     | 0.1 <sup>b</sup> | 17 <sup>b</sup>   | 5 <sup>b</sup>     | 2.7 <sup>b</sup>   | -    |

a EMEP/CORINAIR (1996)

b IPCC(1997)

Military aviation emissions cannot be estimated in this way since LTO data are not available. A first estimate of military emissions is made using military fuel consumption data and IPCC (1997) and EMEP/CORINAIR (1999) cruise defaults shown in Table 1. The EMEP/CORINAIR (1999) factors used are appropriate for military aircraft. The military fuel data includes fuel consumption by all military services in the UK. It also includes fuel shipped to overseas garrisons, casual uplift at civilian airports, but not fuel uplifted at foreign military airfields or *ad hoc* uplift from civilian airfields.

## 5.2 RAILWAYS

The UK GHGI reports emissions from both stationary and mobile sources. The source, railways (stationary) reports emissions from the combustion of burning oil, fuel oil and natural gas by the railway sector. The natural gas emission derives from generation plant used for the London Underground. These stationary emissions are reported under 1A4a Commercial /Institutional in the IPCC reporting system. Most of the electricity used by the railways for electric traction is supplied from the public distribution system, so the emissions arising from its generation are reported under 1A1a Public Electricity. These emissions are based on fuel consumption data from DTI (2000). Emission factors are reported in Tables 1 to 3.

The NAEI reports emissions from diesel trains as railways (freight), railways (intercity) and railways (regional). These estimates are based on the gas oil consumption for railways reported in DTI (2000). Emissions from diesel trains are reported under the IPCC category 1A3c Railways

Diesel train journeys have been split into three categories: freight, intercity and regional. Carbon dioxide, sulphur dioxide and N<sub>2</sub>O emissions are calculated based on fuel based emission factors using fuel consumption data from DTI (2000). This fuel consumption is distributed according to railway km data from DETR (1996c) on the three types of journey; an assumed mix of locomotives for each journey type; and fuel consumption factors for the different types of locomotive (LRC, 1998). The detailed railway km data are only available up to 1995 and later years are interpolated using 1995 data. Emissions of CO, NMVOG, NO<sub>x</sub> and methane are

based on the railway km estimates and emission factors for the various types of locomotive used. The emission factors shown in Table 10 are aggregate factors so that all factors are reported on the common basis of fuel consumption.

Table 10: Railway Emission Factors (kt/Mt)

|           | CO <sub>2</sub> | CH <sub>4</sub> | N <sub>2</sub> O | NO <sub>x</sub> | CO  | NM VOC | SO <sub>2</sub> |
|-----------|-----------------|-----------------|------------------|-----------------|-----|--------|-----------------|
| Freight   | 857             | 0.14            | 1.2              | 17.5            | 4.9 | 3.6    | 2.8             |
| Intercity | 857             | 0.14            | 1.2              | 27.8            | 8.2 | 3.7    | 2.8             |
| Regional  | 857             | 0.045           | 1.2              | 40.5            | 8.9 | 1.2    | 2.8             |

## 5.3 ROAD TRANSPORT

Emissions from road transport are calculated either from a combination of total fuel consumption data and fuel properties or from a combination of drive related emission factors and road traffic data.

### 5.3.1 Improvements to the 1999 inventory

The only change to the road traffic estimates result from revisions in the timeseries of vehicle km data used.

### 5.3.2 Fuel-based emissions

Emissions of carbon dioxide and sulphur dioxide from road transport are calculated from the consumption of petrol and diesel fuels and the sulphur content of the fuels consumed. Data on petrol and diesel fuels consumed by road transport in the UK are taken from the Digest of UK Energy Statistics published by the DTI and corrected for consumption by off-road vehicles.

In 1999, 21.5 Mtonnes of petrol and 15.2 Mtonnes of diesel fuel (DERV) were consumed in the UK. It was estimated that of this around 0.9% of petrol was consumed by off-road vehicles and machinery, leaving 21.3 Mtonnes of petrol consumed by road vehicles in 1999. Around 87% of the petrol sold in the UK was unleaded.

Emissions of CO<sub>2</sub>, expressed as kg carbon per tonne of fuel, are based on the H/C ratio of the fuel; emissions of SO<sub>2</sub> are based on the sulphur content of the fuel. Values of the fuel-based emission factors for CO<sub>2</sub> and SO<sub>2</sub> from consumption of petrol and diesel fuels are shown in Table 11. Values for SO<sub>2</sub> vary annually as the sulphur-content of fuels change and are shown in Table 11 for 1999 fuels based on data from UKPIA (2000).

Table 11 Fuel-Based Emission Factors for Road Transport in kg/tonne fuel

|        | C <sup>a</sup> | SO <sub>2</sub> <sup>b</sup> |
|--------|----------------|------------------------------|
| Petrol | 855            | 0.473                        |
| Diesel | 857            | 0.145                        |

a Emission factor in kg carbon/tonne, based on UKPIA (1989)

b 1999 emission factor calculated from UKPIA (2000) figures on the weighted average sulphur-content of fuels delivered in the UK in 1999

Emissions of CO<sub>2</sub> and SO<sub>2</sub> can be broken down by vehicle type based on estimated fuel consumption factors and traffic data in a manner similar to the traffic-based emissions described below for other pollutants. The 1999 inventory used fuel consumption factors expressed as g fuel per kilometre for each vehicle type and average speed calculated from the emission functions and speed-coefficients provided by COPERT II (European Environment Agency, 1997). Average fuel consumption factors calculated from these functions are shown in Table 12 for each vehicle type, emission regulation and road type in the UK. A normalisation procedure was used to ensure that the breakdown of petrol and diesel consumption by each vehicle type calculated on the basis of the fuel consumption factors added up to the DTI figures for total fuel consumption in the UK (adjusted for off-road consumption).

### 5.3.3 Traffic-based emissions

Emissions of the pollutants NMVOCs, NO<sub>x</sub>, CO, CH<sub>4</sub> and N<sub>2</sub>O are calculated from measured emission factors expressed in grammes per kilometre and road traffic statistics from the Department of Environment, Transport and the Regions (DETR, 2000a). The emission factors are based on experimental measurements of emissions from in-service vehicles of different types driven under test cycles with different average speeds. The road traffic data used are vehicle kilometre estimates for the different vehicle types and different road classifications in the UK road network. These data have to be further broken down by composition of each vehicle fleet in terms of the fraction of diesel- and petrol-fuelled vehicles on the road and in terms of the fraction of vehicles on the road made to the different emission regulations which applied when the vehicle was first registered. These are related to the age profile of the vehicle parc.

Emissions from motor vehicles fall into three different types which are each calculated in a different manner. These are hot exhaust emissions, cold-start emissions and, for NMVOCs, evaporative emissions.

#### 5.3.3.1 Hot exhaust emissions

Hot exhaust emissions are emissions from the vehicle exhaust when the engine has warmed up to its normal operating temperature. Emissions depend on the type of vehicle, the type of fuel its engine runs on, the driving profile of the vehicle on a journey and the emission regulations which applied when the vehicle was first registered as this defines the type of technology the vehicle is equipped with which effects emissions.

Table 12 Fuel Consumption Factors for Road Transport (in g fuel/km)

|             | Emission Standard | Urban | Rural single c/way | Rural dual c/way | Motorway |
|-------------|-------------------|-------|--------------------|------------------|----------|
| Petrol cars | Pre-ECE           | 73.4  | 62.2               | 76.3             | 74.9     |
|             | ECE 15.00         | 62.3  | 48.9               | 61.6             | 60.0     |
|             | ECE 15.01         | 62.3  | 48.9               | 61.6             | 60.0     |
|             | ECE 15.02         | 57.5  | 49.5               | 63.5             | 61.8     |
|             | ECE 15.03         | 57.5  | 49.5               | 63.5             | 61.8     |
|             | ECE 15.04         | 51.8  | 47.1               | 57.1             | 55.6     |
|             | Euro I            | 57.6  | 46.8               | 72.3             | 69.0     |
|             | Euro II           | 57.6  | 46.8               | 72.3             | 69.0     |
| Diesel cars | Pre-Euro I        | 55.7  | 41.5               | 61.7             | 58.9     |
|             | Euro I            | 42.4  | 30.1               | 36.2             | 35.1     |
|             | Euro II           | 42.4  | 30.1               | 36.2             | 35.1     |
| Petrol LGVs | Pre-Euro I        | 76.6  | 60.4               | 90.7             | 86.6     |
|             | Euro I            | 76.6  | 60.4               | 90.7             | 86.6     |
|             | Euro II           | 76.6  | 60.4               | 90.7             | 86.6     |
| Diesel LGV  | Pre-Euro I        | 70.5  | 75.2               | 143.9            | 136.2    |
|             | Euro I            | 88.3  | 75.8               | 101.6            | 98.2     |
|             | Euro II           | 88.3  | 75.8               | 101.6            | 98.2     |
| Rigid HGVs  | Old               | 168   | 155                | 175              | 181      |
|             | Pre-Euro I        | 168   | 155                | 175              | 181      |
|             | Euro I            | 168   | 155                | 175              | 181      |
|             | Euro II           | 168   | 155                | 175              | 181      |
| Artic HGVs  | Old               | 364   | 299                | 311              | 319      |
|             | Pre-Euro I        | 364   | 299                | 311              | 319      |
|             | Euro I            | 364   | 299                | 311              | 319      |
|             | Euro II           | 364   | 299                | 311              | 319      |
| Buses       | Old               | 415   | 203                | 202              | 206      |
|             | Pre-Euro I        | 415   | 203                | 202              | 206      |
|             | Euro I            | 415   | 203                | 202              | 206      |
|             | Euro II           | 415   | 203                | 202              | 206      |
| Motorcycles | <50cc             | 25.0  | 25.0               | 25.0             | 25.0     |
|             | >50cc 2st         | 30.1  | 33.1               | 38.7             | 38.2     |
|             | >50cc, 4st        | 28.5  | 30.7               | 39.8             | 38.8     |

For a particular vehicle, the drive cycle over a journey is the key factor which determines the amount of pollutant emitted. Key parameters affecting emissions are the acceleration, deceleration, steady speed and idling characteristics of the journey, as well as other factors affecting load on the engine such as road gradient and vehicle weight. However, work has shown that for modelling vehicle emissions for an inventory covering a road network on a national scale, it is sufficient to calculate emissions from emission factors in g/km related to the average speed of the vehicle in the drive cycle (Zachariadis and Samaras, 1997). Emission factors for average speeds on the road network are then combined with the national road traffic data.

#### 5.3.3.1.1 Vehicle and fuel type

Emissions are calculated from vehicles of the following types:

- Petrol cars
- Diesel cars
- Petrol Light Goods Vehicles (Gross Vehicle Weight (GVW) = 3.5 tonnes)
- Diesel Light Goods Vehicles (Gross Vehicle Weight (GVW) = 3.5 tonnes)
- Rigid-axle Heavy Goods Vehicles (GVW > 3.5 tonnes)
- Articulated Heavy Goods Vehicles (GVW > 3.5 tonnes)
- Buses and coaches
- Motorcycles

Total emission rates are calculated by multiplying emission factors in g/km with annual vehicle kilometre figures for each of these vehicle types on different types of roads.

#### 5.3.3.1.2 Vehicle kilometres by road type

Hot exhaust emission factors are dependent on average vehicle speed and therefore the type of road the vehicle is travelling on. Average emission factors are calculated for average speeds on four specified types of roads and combined with the number of vehicle kilometres travelled by each type of vehicle on each of these road types:

- Urban
- Rural single carriageway
- Rural dual carriageway
- Motorway

DETR estimate annual vehicle kilometres for the road network in Great Britain by vehicle type on roads classified as trunk, principal and minor roads in built-up areas (urban) and non-built-up areas (rural) and motorways (DETR, 2000a). These estimates are based on traffic counts from the rotating census and core census surveys (DETR, 2000b). Traffic data for Northern Ireland in 1998 and 1999 had not become available by the time the inventory was prepared, so these were estimated by assuming that the vehicle kilometres for each vehicle type and road class in Northern Ireland had grown from 1997 by the same proportion as growth occurred in Great Britain. The 1997 vehicle kilometre data for Northern Ireland came from the Transportation Unit of the Department of the Environment for Northern Ireland (DoE, N. Ireland, 1997).

These data have been combined with the DETR data for Great Britain to produce a time-series of total UK vehicle kilometres by vehicle and road type from 1970 to 1999.

The vehicle kilometre data were grouped into the four road types mentioned above for combination with the associated hot exhaust emission factors.

#### 5.3.3.1.3 Vehicle speeds by road type

Average speed data for traffic in a number of different urban areas have been published in a series of DETR reports based on measured traffic speed surveys (DETR, 1998a, 1998b, 1998c, 1998d, 2000b). These data were rationalised with speed data from other DETR sources, including the 1997 National Road Traffic Forecasts (DETR, 1997) which give average speeds for different urban area sizes, and consolidated with average speed data for unconstrained rural roads and motorways published in Transport Statistics Great Britain (DETR, 2000b). They are shown in Table 13. The speeds are averages of speeds at different times of day and week, weighted by the level of traffic at each of these time periods where this information is known.

Weighting by the number of vehicle kilometres on each of the urban road types gives an overall average speed for urban roads of 43 kph.

#### 5.3.3.1.4 Vehicle split by age and fuel type - fleet composition model

The vehicle kilometres data based on traffic surveys do not distinguish between the type of fuels the vehicles are being run on (petrol and diesel) nor on their age. The latter determines the type of emission regulation that applied when the vehicle was first registered. These have successively entailed the introduction of tighter emission control technologies, for example three-way catalysis, fuel injection systems and better engine management systems.

Table 14 shows the regulations which have come into force up to 1999 for each vehicle type.

The average age profile and the fraction of petrol and diesel cars and LGVs in the traffic flow each year are based on the composition of the UK vehicle fleet using DETR Vehicle Licensing Statistics. The Transport Statistics Bulletin "Vehicle Licensing Statistics: 1999" (DETR, 2000c) either gives historic trends in the composition of the UK fleet directly or provides sufficient information for this to be calculated from new vehicle registrations and average vehicle survival rates. The vehicle licensing data are combined with data on the change in annual vehicle mileage with age to take account of the fact that newer vehicles on average travel a greater number of kilometres in a year than older vehicles. For cars and LGVs, such mileage data are from the National Travel Survey (DETR, 1998e); data for HGVs of different weights are taken from the Continuous Survey of Road Goods Transport (DETR, 1996a).

The fraction of diesel cars and LGVs in the fleet was taken from data in "Vehicle Licensing

Year-of-first registration data for vehicles licensed in each year from 1990 to 1999 taken from DETR's Vehicle Licensing Statistics reflect the age distribution of the fleet in these years.

Table 13 Average Traffic Speeds in Great Britain

| <b>URBAN ROADS</b>  |                     | kph |
|---------------------|---------------------|-----|
| Central London      | Major/trunk A roads | 18  |
|                     | Other A roads       | 14  |
|                     | Minor roads         | 16  |
| Inner London        | Major/trunk A roads | 28  |
|                     | Other A roads       | 20  |
|                     | Minor roads         | 20  |
| Outer London        | Major/trunk A roads | 45  |
|                     | Other A roads       | 26  |
|                     | Minor roads         | 29  |
| Urban motorways     |                     | 95  |
| Large conurbations  | Central             | 34  |
|                     | Outer trunk/A roads | 45  |
|                     | Outer minor roads   | 34  |
| Urban, pop >200,000 | Central             | 37  |
|                     | Outer trunk/A roads | 50  |
|                     | Outer minor roads   | 37  |
| Urban, pop >100,000 | Central             | 40  |
|                     | Outer trunk/A roads | 54  |
|                     | Outer minor roads   | 40  |
| Urban >25 sq km     | Major roads         | 46  |
|                     | Minor roads         | 42  |
| Urban 15-25 sq km   | Major roads         | 49  |
|                     | Minor roads         | 46  |
| Urban 5-15 sq km    | Major roads         | 51  |
|                     | Minor roads         | 48  |
| Urban < 5sq km      | Major roads         | 52  |
|                     | Minor roads         | 48  |

Table 13 Continued

| <b>RURAL ROADS</b>       |             | Lights<br>kph | Heavies<br>kph |
|--------------------------|-------------|---------------|----------------|
| Rural single carriageway | Major roads | 80            | 75             |
|                          | Minor roads | 67            | 63             |
| Rural dual carriageway   |             | 113           | 89             |
| Rural motorway           |             | 113           | 92             |

Table 14 Vehicle Types and Regulation Classes

| <b>Vehicle Type</b> | <b>Fuel</b>        | <b>Regulation</b>   | <b>Approximate date into service in UK</b>                                       |
|---------------------|--------------------|---|--|
| Cars                | Petrol             | Pre ECE-15.00<br>ECE-15.00<br>ECE-15.01<br>ECE-15.02<br>ECE-15.03<br>ECE-15.04<br>91/441/EEC (Euro I)<br>94/12/EC (Euro II) | 1/1/1971<br>1/7/1975<br>1/7/1976<br>1/7/1979<br>1/7/1983<br>1/7/1992<br>1/1/1997 |
|                     | Diesel             | Pre-Euro I<br>91/441/EEC (Euro I)<br>94/12/EC (Euro II)   | 1/1/1993<br>1/1/1997   |
| LGV                 | Petrol             | Pre-Euro I<br>93/59/EEC (Euro I)<br>Euro II   | 1/7/1994<br>1/7/1997   |
|                     | Diesel             | Pre-Euro I<br>93/59/EEC (Euro I)<br>Euro II   | 1/7/1994<br>1/7/1997   |
| HGV                 | Diesel (All types) | Old<br>Pre-Euro I<br>91/542/EEC (Euro I)<br>Euro II   | 1/10/1988<br>1/10/1993<br>1/10/1996  |
| Buses and coaches   | Diesel             | Old<br>Pre-Euro I<br>91/542/EEC (Euro I)<br>Euro II   | 1/10/1988<br>1/10/1993<br>1/10/1996  |
| Motorcycles         | Petrol             | Current < 50cc<br>Current >50cc, 2 stroke<br>Current >50cc, 4 stroke  |  |



Statistics are also available on the number of new registrations in each year up to 1999, reflecting the number of new vehicles entering into service in previous years. The two sets of data combined allow an average survival rate to be determined for each type of vehicle. Particularly detailed information is available on the composition of the HGV stock by age and size.

It is assumed that the catalysts fail in 5% of cars fitted with them each year (for example due to mechanical damage of the catalyst unit) and that 95% of failed catalysts will be repaired each year, but only for cars more than three years in age, when they first reach the age for MOT testing.

The 1999 inventory took into account voluntary measures to reduce emissions from road vehicles. The Euro III emission standards for passenger cars (98/69/EC) come into effect from January 2001 (new registrations). However, some makes of cars sold in the UK already meet the Euro III standards (DETR, 1999d). Figures from the Society of Motor Manufacturers and Traders suggested that 3.7% of new cars sold in 1998 met Euro III standards (SMMT, 1999). Figures were not available for 1999, but it was assumed that 5% of new car sales met Euro III standards. This was taken into account in the emission estimates for 1999.

Information from the bus industry suggested that around 5% of buses in 1997 and 10% in 1998 were fitted with oxidation catalysts to reduce emissions (LT Buses, 1998). A large proportion of buses were run on ultra-low sulphur diesel from 1997 to 1999. Based on information from the Confederation of Passenger Transport (1999) and individual bus operators (e.g. LT Buses, 1998), the proportions running on ULS diesel rose from around 10% in 1997 to 80% in 1999. These factors were taken into account in the 1999 inventory. Freight haulage operators are now looking at incentives to upgrade the engines in their HGVs or retrofit them with particle traps. However, the number of HGVs modified in this way is still very small so were not included in the inventory.

Detailed information from DVLA was used on the composition of the motorcycle fleet in terms of engine capacity (DETR, 2000c). The information was used to calculate the proportion of motorcycles on the road less than 50cc (i.e. mopeds), >50cc, 2-stroke and >50cc, 4-stroke.

#### 5.3.3.1.5 Hot emission factors

The emission factors for NO<sub>x</sub>, CO and NMVOCs used for the 1998 inventory are based on data from TRL (Hickman, 1998) and COPERT II, "*Computer Programme to Calculate Emissions from Road Transport*" produced by the European Topic Centre on Air Emissions for the European Environment Agency (1997). Both these sources provide emission functions and coefficients relating emission factor (in g/km) to average speed for each vehicle type and Euro emission standard derived by fitting experimental measurements to some polynomial functional form.

These functions were then used to calculate emission factor values for each vehicle type and Euro emission standard at each of the average speeds of the road and area types shown in Table 13. The calculated values were averaged to produce single emission factors for the four main road classes described earlier (urban, rural single carriageway, rural dual carriageway and motorway), weighted by the estimated vehicle kilometres on each of the detailed road types taken from the 1997 NRTF (DETR, 1997).

Whenever possible, the emission factors were calculated from the equations provided by TRL (Hickman, 1998) from analysis of data gathered from measurements of on-road vehicles of different ages tested on rolling roads or engine test beds. The measurements were made by TRL on UK vehicles or were drawn from the Workbook of Emission Factors for Road Transport produced at UBA Berlin (Infras, 1995). Where data were unavailable from TRL for particular Euro standards, the data were taken from the equations recommended by COPERT II. For the same pollutant, vehicle type and emission standard, the TRL and COPERT II data gave broadly similar emission factors.

For the more recent Euro II standard (and Euro I for some vehicle types), there have not yet been any measurements of emissions from in-service vehicles. Therefore, emission factors were calculated using scaling factors relative to Euro I values taken from COPERT II or Gover et al. (1994). Similarly, emission factors for the new Euro III cars were calculated using scaling factors described elsewhere (Murrells, 2000), based on the Type-Approval Limit Values for new vehicles and assessments on the effectiveness of different abatement technology concepts.

For each type of vehicle, both TRL and COPERT II provide equations for different ranges of vehicle engine capacity or vehicle weight; emission factors calculated from these equations were therefore averaged, weighted according to the proportion of the different vehicle sizes in the UK fleet, to produce a single average emission factor for each vehicle type. These average emission factors are given in Tables 16 to 20 for each of the different vehicle types and emission regulations.

Speed-dependent functions provided by TRL (Hickman, 1998) for different sizes of motorcycles were used. All motorcycles are assumed to be uncontrolled. It was also assumed that mopeds (<50cc) operate only in urban areas, while the only motorcycles on motorways are the type more than 50cc, 4-stroke. Otherwise, the number of vehicle kilometres driven on each road type were disaggregated by motorcycle type according to the proportions in the fleet.

Emissions from buses were scaled down according to the proportion running on ultra-low sulphur diesel fuel in each year, the proportion fitted with oxidation catalysts and the effectiveness of these measures in reducing emissions from the vehicles. The percentage effectiveness of these measures in reducing emissions from a Euro II vehicle varies for each pollutant and is shown in Table 15. It is assumed that a bus fitted with an oxidation catalyst is also running on ULS diesel.

Table 15 Scale Factors for Emissions from a Euro II Bus Running on Ultra-Low Sulphur Diesel and Fitted with an Oxidation Catalyst

|                           |       | <b>NO<sub>x</sub></b> | <b>CO</b> | <b>NMVOCs</b> |
|---------------------------|-------|-----------------------|-----------|---------------|
| ULS diesel only           | Urban | 1.01                  | 0.91      | 0.72          |
|                           | Rural | 0.99                  | 1.01      | 1.02          |
| ULS diesel + Oxy catalyst | Urban | 0.97                  | 0.20      | 0.39          |
|                           | Rural | 0.95                  | 0.22      | 0.55          |

These scale factors are relative to emissions from a bus running on 500ppm S diesel and are based on analysis of fuel quality effects by Murrells (2000) and data on the effectiveness of oxidation catalysts on bus emissions by LT Buses (1998).

The older in-service vehicles in the test surveys that were manufactured to a particular emission standard would have covered a range of different ages. Therefore, an emission factor calculated for a particular emission standard (e.g. ECE 15.04) from the emission functions and coefficients from TRL and COPERT II is effectively an average value for vehicles of different ages which inherently takes account of possible degradation in emissions with vehicle age. However, for the more recent emission standards (Euro I and II), the vehicles would have been fairly new when the emissions were measured. Therefore, based on data from the European Auto-Oil study, the deterioration in emissions with age or mileage was taken into account for catalyst cars. It was assumed that emissions of CO and NO<sub>x</sub> increase by 60% over 80,000 km, while emissions of NMVOCs increase by 30% over the same mileage (DETR, 1996b). Based on the average annual mileage of cars, 80,000 km corresponds to a time period of 6.15 years.

Hot emission factors for methane and nitrous oxide were taken from estimates for European vehicles and emission control technologies published in the IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories and are shown in Tables 19 and 20 (IPCC, 1997). Fewer measurements have been made on emissions of these pollutants from vehicles. Therefore, only average emission factors are used, covering all vehicle speed or road types. Their uncertainties can be expected to be quite large. However, the emission factors used reflect the fact that three-way catalysts are less efficient in removing methane from the exhausts than other hydrocarbons and also lead to higher N<sub>2</sub>O emissions than non-catalyst vehicles.

### 5.3.3.2 Cold-Start Emissions

When a vehicle's engine is cold it emits at a higher rate than when it has warmed up to its designed operating temperature. This is particularly true for petrol engines and the effect is even more severe for cars fitted with three-way catalysts, as the catalyst does not function properly until the catalyst is also warmed up. Emission factors have been derived for cars and LGVs from tests performed with the engine starting cold and warmed up. The difference between the two measurements can be regarded as an additional cold-start penalty paid on each trip a vehicle is started with the engine (and catalyst) cold.

The procedure for estimating cold-start emissions is taken from COPERT II (European Environment Agency, 1997), taking account of the effects of ambient temperature on emission factors for different vehicle technologies and its effect on the distance travelled with the engine cold. A factor, the ratio of cold to hot emissions, is used and applied to the fraction of

kilometres driven with cold engines to estimate the cold start emissions from a particular vehicle type using the following formula:

$$E_{\text{cold}} = \beta \cdot E_{\text{hot}} \cdot (e^{\text{cold}}/e^{\text{hot}} - 1)$$

where:  $E_{\text{hot}}$  = hot exhaust emissions from the vehicle type  
 $\beta$  = fraction of kilometres driven with cold engines  
 $e^{\text{cold}}/e^{\text{hot}}$  = ratio of cold to hot emissions for the particular pollutant and vehicle type

The parameters  $\beta$  and  $e^{\text{cold}}/e^{\text{hot}}$  are both dependent on ambient temperature and  $\beta$  is also dependent on driving behaviour, in particular the average trip length as this determines the time available for the engine and catalyst to warm up. The equations relating  $e^{\text{cold}}/e^{\text{hot}}$  to ambient temperature for each pollutant and vehicle type were taken from COPERT II and were used with an annual mean temperature for the UK of 11°C. This is based on historic trends in Met Office data for ambient temperatures over different parts of the UK.

The factor  $\beta$  is related to ambient temperature and average trip length by the following equation taken from COPERT II:

$$\beta = 0.698 - 0.051 \cdot l_{\text{trip}} - (0.01051 - 0.000770 \cdot l_{\text{trip}}) \cdot t_a$$

where:  $l_{\text{trip}}$  = average trip length  
 $t_a$  = average temperature.

An average trip length for the UK of 8.4 km was used, taken from Andre *et al* (1993). This gives a value for  $\beta$  of 0.23.

This methodology was used to estimate annual UK cold start emissions of NO<sub>x</sub>, CO and NMVOCs from petrol and diesel cars and LGVs. Emissions were calculated separately for catalyst and non-catalyst petrol vehicles. Cold start emissions data are not available for heavy duty vehicles, but these are thought to be negligible (Boulter, 1996).

All the cold start emissions are assume to apply to urban driving.

Cold-start emissions data are not available for the pollutants methane and nitrous oxide.

### 5.3.3.3 Evaporative Emissions

Evaporative emissions of petrol fuel vapour from the tank and fuel delivery system in vehicles constitute a significant fraction of total NMVOC emissions from road transport. The procedure for estimating evaporative emissions of NMVOCs takes account of changes in ambient temperature and fuel volatility.

There are three different mechanisms by which gasoline fuel evaporates from vehicles:-

**i) Diurnal loss**

This arises from the increase in the volatility of the fuel and expansion of the vapour in the fuel tank due to the diurnal rise in ambient temperature. Evaporation through “tank breathing” will occur each day for all vehicles with gasoline fuel in the tank, even when stationary.

**ii) Hot soak loss**

This represents evaporation from the fuel delivery system when a hot engine is turned off and the vehicle is stationary. It arises from transfer of heat from the engine and hot exhaust to the fuel system where fuel is no longer flowing. Carburettor float bowls contribute significantly to hot soak losses.

**iii) Running loss**

These are evaporative losses that occur while the vehicle is in motion.

Evaporative emissions are dependent on ambient temperature and the volatility of the fuel and, in the case of diurnal losses, on the daily *rise* in ambient temperature. Fuel volatility is usually expressed by the empirical fuel parameter known as Reid vapour pressure (RVP). For each of these mechanisms, equations relating evaporative emissions to ambient temperature and RVP were developed by analysis of empirically-based formulae derived in a series of CONCAWE research studies in combination with UK measurements data reported by TRL. Separate equations were developed for vehicles with and without evaporative control systems fitted such as carbon canister devices. The overall methodology is similar to that reported by COPERT II (European Environment Agency, 1997), but the data are considered to be more UK-biased.

All the equations for diurnal, hot soak and running loss evaporative emissions from vehicles with and without control systems fitted developed for the inventory are shown in Table 21.

For **diurnal losses**, the equations were developed from data and formulae reported by CONCAWE (1987), TRL (1993) and ACEA (1995). Based on historic trends in Met Office temperature data for the UK, an average maximum daily temperature of 15°C and an average daily diurnal rise in temperature of 9°C was used. Current market fuel has an RVP of around 74kPa in summer blends (June - August) and 94 kPa in winter blends (September - May) (Watson, 1999). An annual average value of 90 kPa was used.

The equations specified in Table 21 give diurnal loss emissions in g/vehicle.day for uncontrolled ( $DL_{\text{uncontrolled}}$ ) and canister controlled ( $DL_{\text{controlled}}$ ) vehicles. Total annual diurnal losses were calculated from the equation:

$$E_{\text{diurnal}} = 365 \cdot N \cdot (DL_{\text{uncontrolled}} \cdot (1 - F_{\text{controlled}}) + DL_{\text{controlled}} \cdot F_{\text{controlled}})$$

where:

$N$  = Number of petrol vehicles (cars and LGVs) in the UK parc  
 $F_{\text{controlled}}$  = fraction of vehicles fitted with carbon canisters, assumed to be the same as the fraction of vehicles fitted with a three-way catalyst

For **hot soak losses**, the equations were developed from data and formulae reported by CONCAWE (1990), TRL (1993) and COPERT II. Based on historic trends in Met Office temperature data for the UK, an annual mean temperature for the UK of 11°C were used.

The equations specified in Table 21 give hot soak loss emissions in g/vehicle.trip for uncontrolled ( $HS_{\text{uncontrolled}}$ ) and canister controlled ( $HS_{\text{controlled}}$ ) vehicles. Total annual hot soak losses were calculated from the equation:

$$E_{\text{hot soak}} = (\text{VKM} / l_{\text{trip}}) \cdot (HS_{\text{uncontrolled}} \cdot (1 - F_{\text{controlled}}) + HS_{\text{controlled}} \cdot F_{\text{controlled}})$$

where:

VKM = total number of vehicle kilometres driven in the UK by the petrol vehicles (cars and LGVs)

$l_{\text{trip}}$  = average trip length (8.4 km in the UK)

$F_{\text{controlled}}$  = fraction of vehicles fitted with carbon canisters, assumed to be the same as the fraction of vehicles fitted with a three-way catalyst

For **running losses**, the equations were developed from data and formulae reported by CONCAWE (1990) and COPERT II.

The equations specified in Table 21 give running loss emissions in g/vehicle.km for uncontrolled ( $RL_{\text{uncontrolled}}$ ) and canister controlled ( $RL_{\text{controlled}}$ ) vehicles. Total annual running losses were calculated from the equation:

$$E_{\text{running loss}} = \text{VKM} \cdot (RL_{\text{uncontrolled}} \cdot (1 - F_{\text{controlled}}) + RL_{\text{controlled}} \cdot F_{\text{controlled}})$$

Table 16 NMVOC Emission Factors for Road Transport (in g/km)

| Emission Standard |            | Urban | Rural single c/way | Rural dual c/way | Motorway |
|-------------------|------------|-------|--------------------|------------------|----------|
| Petrol cars       | Pre-ECE    | 2.30  | 1.54               | 1.25             | 1.25     |
|                   | ECE 15.00  | 1.80  | 1.23               | 1.08             | 1.09     |
|                   | ECE 15.01  | 1.80  | 1.23               | 1.08             | 1.09     |
|                   | ECE 15.02  | 1.81  | 1.04               | 0.95             | 0.95     |
|                   | ECE 15.03  | 1.81  | 1.04               | 0.95             | 0.95     |
|                   | ECE 15.04  | 1.50  | 0.93               | 0.80             | 0.80     |
|                   | Euro I     | 0.14  | 0.08               | 0.14             | 0.13     |
|                   | Euro II    | 0.096 | 0.056              | 0.097            | 0.090    |
| Diesel cars       | Pre-Euro I | 0.153 | 0.087              | 0.059            | 0.061    |
|                   | Euro I     | 0.060 | 0.028              | 0.014            | 0.015    |
|                   | Euro II    | 0.042 | 0.019              | 0.010            | 0.010    |
| Petrol LGVs       | Pre-Euro I | 1.71  | 0.77               | 1.14             | 1.05     |
|                   | Euro I     | 0.09  | 0.09               | 0.19             | 0.18     |
|                   | Euro II    | 0.06  | 0.06               | 0.13             | 0.12     |
| Diesel LGV        | Pre-Euro I | 0.30  | 0.16               | 0.19             | 0.18     |
|                   | Euro I     | 0.23  | 0.13               | 0.10             | 0.10     |
|                   | Euro II    | 0.16  | 0.09               | 0.07             | 0.07     |
| Rigid HGVs        | Old        | 6.42  | 3.21               | 3.21             | 3.21     |
|                   | Pre-Euro I | 1.84  | 1.44               | 1.39             | 1.39     |
|                   | Euro I     | 1.08  | 0.71               | 0.59             | 0.57     |
|                   | Euro II    | 1.00  | 0.65               | 0.53             | 0.52     |
| Artic HGVs        | Old        | 6.78  | 3.21               | 3.21             | 3.21     |
|                   | Pre-Euro I | 1.63  | 1.05               | 0.86             | 0.83     |
|                   | Euro I     | 0.97  | 0.68               | 0.59             | 0.57     |
|                   | Euro II    | 0.89  | 0.61               | 0.51             | 0.49     |
| Buses             | Old        | 5.80  | 2.60               | 2.60             | 2.30     |
|                   | Pre-Euro I | 1.93  | 0.53               | 0.50             | 0.50     |
|                   | Euro I     | 1.91  | 0.64               | 0.52             | 0.50     |
|                   | Euro II    | 1.79  | 0.56               | 0.45             | 0.44     |
| Motorcycles       | <50cc      | 12.30 | 18.50              | 26.18            | 25.53    |
|                   | >50cc 2st  | 9.52  | 8.28               | 8.34             | 8.29     |
|                   | >50cc, 4st | 1.83  | 1.27               | 1.28             | 1.26     |

Table 17 NO<sub>x</sub> Emission Factors for Road Transport (in g/km)

| Emission Standard |            | Urban | Rural single c/way | Rural dual c/way | Motorway |
|-------------------|------------|-------|--------------------|------------------|----------|
| Petrol cars       | Pre-ECE    | 2.10  | 2.53               | 2.84             | 2.82     |
|                   | ECE 15.00  | 2.10  | 2.53               | 2.84             | 2.82     |
|                   | ECE 15.01  | 2.10  | 2.53               | 2.84             | 2.82     |
|                   | ECE 15.02  | 1.79  | 2.38               | 3.61             | 3.49     |
|                   | ECE 15.03  | 1.92  | 2.61               | 3.99             | 3.86     |
|                   | ECE 15.04  | 1.64  | 2.21               | 3.26             | 3.16     |
|                   | Euro I     | 0.29  | 0.31               | 0.60             | 0.56     |
|                   | Euro II    | 0.143 | 0.157              | 0.298            | 0.281    |
| Diesel cars       | Pre-Euro I | 0.623 | 0.570              | 0.739            | 0.718    |
|                   | Euro I     | 0.392 | 0.223              | 0.296            | 0.282    |
|                   | Euro II    | 0.274 | 0.156              | 0.207            | 0.197    |
| Petrol LGVs       | Pre-Euro I | 1.83  | 2.28               | 3.25             | 3.16     |
|                   | Euro I     | 0.33  | 0.39               | 0.63             | 0.61     |
|                   | Euro II    | 0.16  | 0.20               | 0.32             | 0.30     |
| Diesel LGV        | Pre-Euro I | 1.22  | 1.15               | 1.53             | 1.48     |
|                   | Euro I     | 0.54  | 0.31               | 0.41             | 0.39     |
|                   | Euro II    | 0.38  | 0.21               | 0.28             | 0.27     |
| Rigid HGVs        | Old        | 11.80 | 14.40              | 14.40            | 14.40    |
|                   | Pre-Euro I | 6.02  | 4.96               | 5.65             | 5.91     |
|                   | Euro I     | 3.94  | 3.24               | 3.38             | 3.47     |
|                   | Euro II    | 3.16  | 2.51               | 2.59             | 2.65     |
| Artic HGVs        | Old        | 18.20 | 24.10              | 24.10            | 19.80    |
|                   | Pre-Euro I | 16.93 | 12.93              | 11.69            | 11.52    |
|                   | Euro I     | 9.14  | 6.82               | 5.98             | 5.86     |
|                   | Euro II    | 7.48  | 5.58               | 4.89             | 4.79     |
| Buses             | Old        | 16.20 | 14.80              | 14.80            | 13.50    |
|                   | Pre-Euro I | 13.62 | 5.45               | 5.88             | 6.13     |
|                   | Euro I     | 14.89 | 4.39               | 4.35             | 4.39     |
|                   | Euro II    | 10.63 | 3.59               | 3.56             | 3.59     |
| Motorcycles       | <50cc      | 0.03  | 0.03               | 0.03             | 0.03     |
|                   | >50cc 2st  | 0.03  | 0.07               | 0.13             | 0.13     |
|                   | >50cc, 4st | 0.16  | 0.23               | 0.40             | 0.39     |



Table 18 CO Emission Factors for Road Transport (in g/km)

| Emission Standard |            | Urban | Rural single c/way | Rural dual c/way | Motorway |
|-------------------|------------|-------|--------------------|------------------|----------|
| Petrol cars       | Pre-ECE    | 26.92 | 18.70              | 16.97            | 16.70    |
|                   | ECE 15.00  | 18.43 | 14.85              | 22.20            | 21.32    |
|                   | ECE 15.01  | 18.43 | 14.85              | 22.20            | 21.32    |
|                   | ECE 15.02  | 15.50 | 8.03               | 9.74             | 9.38     |
|                   | ECE 15.03  | 15.94 | 8.37               | 9.22             | 8.84     |
|                   | ECE 15.04  | 10.10 | 6.34               | 7.97             | 7.64     |
|                   | Euro I     | 1.40  | 1.22               | 4.32             | 3.96     |
|                   | Euro II    | 1.261 | 1.095              | 3.885            | 3.560    |
| Diesel cars       | Pre-Euro I | 0.686 | 0.456              | 0.426            | 0.423    |
|                   | Euro I     | 0.394 | 0.227              | 0.289            | 0.276    |
|                   | Euro II    | 0.276 | 0.159              | 0.203            | 0.193    |
| Petrol LGVs       | Pre-Euro I | 14.27 | 8.87               | 36.13            | 32.54    |
|                   | Euro I     | 2.78  | 1.42               | 4.40             | 4.01     |
|                   | Euro II    | 2.50  | 1.28               | 3.96             | 3.61     |
| Diesel LGV        | Pre-Euro I | 1.09  | 0.84               | 1.36             | 1.29     |
|                   | Euro I     | 0.82  | 0.57               | 0.80             | 0.76     |
|                   | Euro II    | 0.57  | 0.40               | 0.56             | 0.54     |
| Rigid HGVs        | Old        | 6.00  | 2.90               | 2.90             | 2.90     |
|                   | Pre-Euro I | 2.64  | 2.12               | 1.99             | 1.97     |
|                   | Euro I     | 1.66  | 1.16               | 0.97             | 0.95     |
|                   | Euro II    | 1.45  | 1.07               | 0.92             | 0.90     |
| Artic HGVs        | Old        | 7.30  | 3.70               | 3.70             | 3.10     |
|                   | Pre-Euro I | 3.06  | 2.48               | 2.46             | 2.47     |
|                   | Euro I     | 1.67  | 1.23               | 1.07             | 1.05     |
|                   | Euro II    | 1.39  | 1.15               | 1.07             | 1.05     |
| Buses             | Old        | 18.80 | 7.30               | 7.30             | 1.76     |
|                   | Pre-Euro I | 9.00  | 3.29               | 3.88             | 4.06     |
|                   | Euro I     | 3.77  | 1.08               | 0.89             | 0.86     |
|                   | Euro II    | 3.02  | 0.96               | 0.78             | 0.76     |
| Motorcycles       | <50cc      | 23.81 | 36.46              | 52.13            | 50.80    |
|                   | >50cc 2st  | 23.37 | 25.80              | 28.67            | 28.43    |
|                   | >50cc, 4st | 20.81 | 22.20              | 31.91            | 30.83    |

Table 19 Methane Emission Factors for Road Transport (in g/km)

| Emission standard |                      | Urban | Rural single c/way | Rural dual c/way | Motorway |
|-------------------|----------------------|-------|--------------------|------------------|----------|
| Petrol cars       | Pre- ECE             | 0.080 | 0.080              | 0.080            | 0.080    |
|                   | ECE 15.00            | 0.082 | 0.082              | 0.082            | 0.082    |
|                   | ECE 15.01            | 0.082 | 0.082              | 0.082            | 0.082    |
|                   | ECE 15.02            | 0.082 | 0.082              | 0.082            | 0.082    |
|                   | ECE 15.03            | 0.071 | 0.071              | 0.071            | 0.071    |
|                   | ECE 15.04            | 0.071 | 0.071              | 0.071            | 0.071    |
|                   | Stage I (91/441/EEC) | 0.020 | 0.020              | 0.020            | 0.020    |
|                   | Stage II             | 0.020 | 0.020              | 0.020            | 0.020    |
| Diesel cars       | Pre-Stage I          | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | Stage I              | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | Stage II             | 0.005 | 0.005              | 0.005            | 0.005    |
| Petrol LGV        | Pre-Stage 1          | 0.081 | 0.081              | 0.081            | 0.081    |
|                   | Stage I              | 0.081 | 0.081              | 0.081            | 0.081    |
|                   | Stage II             | 0.081 | 0.081              | 0.081            | 0.081    |
| Diesel LGV        | Pre-Stage 1          | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | Stage I              | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | Stage II             | 0.005 | 0.005              | 0.005            | 0.005    |
| HGV rigid         | Old                  | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Pre-Stage I          | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Stage I              | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Stage II             | 0.063 | 0.063              | 0.063            | 0.063    |
| HGV artic         | Old                  | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Pre-Stage I          | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Stage I              | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Stage II             | 0.063 | 0.063              | 0.063            | 0.063    |
| Buses             | Old                  | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Pre-Stage I          | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Stage I              | 0.063 | 0.063              | 0.063            | 0.063    |
|                   | Stage II             | 0.063 | 0.063              | 0.063            | 0.063    |
| Motorcycles       | < 50 cc              | 0.100 | 0.100              | 0.100            | 0.100    |
|                   | > 50 cc, 2st         | 0.150 | 0.150              | 0.150            | 0.150    |
|                   | > 50 cc, 4st         | 0.200 | 0.200              | 0.200            | 0.200    |

Table 20 N<sub>2</sub>O Emission Factors for Road Transport (in g/km)

| Emission standard |                     | Urban | Rural single c/way | Rural dual c/way | Motorway |
|-------------------|---------------------|-------|--------------------|------------------|----------|
| Petrol cars       | Pre- ECE            | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | ECE 15.00           | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | ECE 15.01           | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | ECE 15.02           | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | ECE 15.03           | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | ECE 15.04           | 0.005 | 0.005              | 0.005            | 0.005    |
|                   | Euro I (91/441/EEC) | 0.050 | 0.050              | 0.050            | 0.050    |
|                   | Euro II             | 0.050 | 0.050              | 0.050            | 0.050    |
| Diesel cars       | Pre-Euro I          | 0.010 | 0.010              | 0.010            | 0.010    |
|                   | Euro I              | 0.010 | 0.010              | 0.010            | 0.010    |
|                   | Euro II             | 0.010 | 0.010              | 0.010            | 0.010    |
| Petrol LGV        | Pre-Euro I          | 0.006 | 0.006              | 0.006            | 0.006    |
|                   | Euro I              | 0.060 | 0.060              | 0.060            | 0.060    |
|                   | Euro II             | 0.060 | 0.060              | 0.060            | 0.060    |
| Diesel LGV        | Pre-Euro I          | 0.017 | 0.017              | 0.017            | 0.017    |
|                   | Euro I              | 0.017 | 0.017              | 0.017            | 0.017    |
|                   | Euro II             | 0.017 | 0.017              | 0.017            | 0.017    |
| HGV rigid         | Old                 | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Pre-Euro I          | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Euro I              | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Euro II             | 0.030 | 0.030              | 0.030            | 0.030    |
| HGV artic         | Old                 | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Pre-Euro I          | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Euro I              | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Euro II             | 0.030 | 0.030              | 0.030            | 0.030    |
| Buses             | Old                 | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Pre-Euro I          | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Euro I              | 0.030 | 0.030              | 0.030            | 0.030    |
|                   | Euro II             | 0.030 | 0.030              | 0.030            | 0.030    |
| Motorcycles       | < 50 cc             | 0.001 | 0.001              | 0.001            | 0.001    |
|                   | > 50 cc, 2st        | 0.002 | 0.002              | 0.002            | 0.002    |
|                   | > 50 cc, 4st        | 0.002 | 0.002              | 0.002            | 0.002    |

Table 21 Equations for diurnal, hot soak and running loss evaporative emissions from vehicles with and without control systems fitted

| <b>Emission factor</b> | <b>Units</b>   | <b>Uncontrolled vehicle</b>   | <b>Carbon canister controlled vehicle</b>                              |
|------------------------|----------------|---|--|
| Diurnal loss (DL)      | g/vehicle.day  | $1.54 * (0.51 * T_{\text{rise}} + 0.62 * T_{\text{max}} + 0.22 * \text{RVP} - 24.89)$ | 0.3 * uncontrolled vehicle emissions                                   |
| Hot soak (HS)          | g/vehicle.trip | $\exp(-1.644 + 0.02 * \text{RVP} + 0.0752 * T_{\text{mean}})$                         | $0.3 * \exp(-2.41 + 0.02302 * \text{RVP} + 0.09408 * T_{\text{mean}})$ |
| Running loss (RL)      | g/vehicle.km   | $0.022 * \exp(-5.967 + 0.04259 * \text{RVP} + 0.1773 * T_{\text{mean}})$              | 0.1 * uncontrolled vehicle emissions                                   |

where:

$T_{\text{rise}}$  = diurnal rise in temperature in °C

$T_{\text{max}}$  = maximum daily temperature in °C

$T_{\text{mean}}$  = annual mean temperature in °C

RVP = Reid Vapour Pressure of petrol in kPa

## 5.4 NAVIGATION

The NAEI estimates emissions from Coastal Shipping, Fishing, Naval Shipping and International Marine. Coastal Shipping has been mapped onto 1A3dii National Navigation and Fishing onto 1A4ciii Fishing. The category Coastal Shipping does contain emissions from offshore diesel oil use. A proportion of this will be marine transport associated with the offshore industry but some is diesel oil use in turbines, motors and heaters on offshore installations. The emissions reported under Coastal Shipping, Naval Shipping and Fishing are estimated according to the base combustion module using the emission factors given in Table 1.

The NAEI category International Marine is the same as the IPCC category 1A3i International Marine. The estimate used is based on the following information and assumptions:

- (i) Total deliveries of fuel oil, gas oil and marine diesel oil to marine bunkers are given in DTI (2000).
- (ii) Naval fuel consumption is assumed to be marine diesel oil (MOD, 2000). Emissions from this source are not included here but are reported under 1A5 Other.
- (iii) The fuel consumption associated with international marine is the marine bunkers total minus the naval consumption. The emissions were estimated using the emission factors shown in Table 1

Emissions from 1A3i International Marine are reported for information only and are not included in national totals.

## 5.5 OTHER SECTORS COMBUSTION

The mapping of NAEI categories to 1A4 Other Sectors is shown in Appendix 1. The estimation procedure follows that of the base combustion module. The NAEI category Public Service is mapped onto 1A4a Commercial and Institutional. This contains emissions from stationary combustion at military installations which should be reported under 1A5a Stationary. Also included are stationary combustion emissions from the railway sector, including generating plant dedicated to railways.

Emissions from 1A4b Residential and 1A4c Agriculture/Forestry/Fishing are disaggregated into those arising from stationary combustion and those from off-road vehicles and other machinery. The estimation of emissions from off-road sources is discussed in Section 5.7. Emissions from fishing vessels are estimated from fuel consumption data (DTI, 2000) and emission factors are shown in Table 1.

## 5.6 OTHER COMBUSTION

Emissions from military aircraft and naval vessels are reported under 1A5b Mobile. The method of estimation is discussed in Sections 5.1 and 5.4 with emission factors given Table 1. Military stationary combustion is included under 1A4a Commercial and Institutional. Emissions from off-road sources are estimated and are reported under the relevant sectors, i.e. Other Industry, Residential, Agriculture and Other Transport. The methodology of these estimates is discussed in Section 5.7

## 5.7 OTHER OFF-ROAD SOURCES

These cover emissions from a range of portable or mobile equipment powered by reciprocating diesel or petrol driven engines. They include agricultural equipment such as tractors and combine harvesters; construction equipment such as bulldozers and excavators; domestic lawn mowers; aircraft support equipment; and industrial machines such as portable generators and compressors. In the NAEI they are grouped into four main categories:

- domestic house & garden
- agricultural power units (includes forestry)
- industrial off-road (includes construction and quarrying)
- aircraft support.

The mapping of these categories to the appropriate IPCC classes is shown in Appendix 1. Aircraft support is mapped to Other Transport and the other categories map to the off-road vehicle subcategories of Residential, Agriculture and Manufacturing Industries and Construction.

The estimates are calculated using a modification of the methodology given in EMEP/CORINAIR (1996). This involves the estimation of emissions from around seventy classes of off-road source using the following equation for each class:

$$E_j = N_j \cdot H_j \cdot P_j \cdot L_j \cdot W_j \cdot (1 + Y_j \cdot a_j / 2) \cdot e_j$$

where

|       |   |                                    |                    |
|-------|---|------------------------------------|--------------------|
| $E_j$ | = | Emission of pollutant from class j | (kg/y)             |
| $N_j$ | = | Population of class j.             |                    |
| $H_j$ | = | Annual usage of class j            | (hours/year)       |
| $P_j$ | = | Average power rating of class j    | (kW)               |
| $L_j$ | = | Load factor of class j             | (-)                |
| $Y_j$ | = | Lifetime of class j                | (years)            |
| $W_j$ | = | Engine design factor of class j    | (-)                |
| $a_j$ | = | Age factor of class j              | (y <sup>-1</sup> ) |
| $e_j$ | = | Emission factor of class j         | (kg/kWh)           |

For petrol engined sources, evaporative NMVOC emissions are also estimated as:

$$E_{vj} = N_j \cdot H_j \cdot e_{vj}$$

where

|          |   |   |      |
|----------|---|---|------|
| $E_{vj}$ | = | Evaporative emission from class j       | kg   |
| $e_{vj}$ | = | Evaporative emission factor for class j | kg/h |

The population and machinery lifetime data have been revised based on a new DETR sponsored survey of machinery sales and lifetime by Off-Highway Research Ltd (2000). These data have been used to revise or supplement the previous activity data sets. These were market research telephone polls amongst equipment suppliers and trade associations by Precision Research International on behalf of DOE. (PRI, 1995, 1998). The annual usage data were taken either from the PRI poll or published data (Samaras *et al*, 1993,1994). The emission factors used came mostly from EMEP/CORINAIR (1996) though a few of the more obscure classes were taken from Samaras *et al* (1993). The load factors were taken from Samaras (1996).

Generally the OHRL data was used to revise the PRI population/lifetime data for sources other than balers, combines, agricultural mowers, agricultural tractors, off-road trucks, fork lifts, generators, cement mixers and lawnmowers where the PRI studies had placed particular effort.

It was possible to calculate fuel consumptions for each class based on fuel consumption factors given in EMEP/CORINAIR (1996). Comparison with known fuel consumption for certain groups of classes (e.g. agriculture and construction) suggested that the population method over estimated fuel consumption by factors of 2-3. Hence the methodology was modified in the following way:

- 1 Aggregate emission factors were calculated for each of the four main categories listed above as

$$e_p = \frac{E}{F}$$

where

$e_p$  = Aggregate emission factor for main NAEI category. (kg/t fuel)

$E$  = Sum of emissions of pollutant from classes within main NAEI category calculated from the population approach (kg)

$F$  = Sum of fuel consumption from classes within main NAEI category calculated from the population approach (tonnes)

- 2 Estimates were derived for the fuel consumptions for the years 1990-1999 for each of the four main categories
  - A. Agricultural power units: Data on gas oil consumption were taken from DTI (2000). The consumption of petrol was estimated using the population method for 1995 without correction. The same estimate was used for 1990 to 1999.
  - B. Aircraft support: Data on diesel oil consumption at Heathrow Airport were extrapolated on the basis of the number of takeoffs and landings (DETR, 1999b; Leech, 1994)
  - C. Industrial off-road: The construction component of the gas oil consumption was calculated from DUKES data (DTI, 2000) on building and contracting; mines and quarrying and water giving a time series for 1990-1999. The industrial component of gas oil was estimated from the population approach. This gave an estimate for 1995 which was used for all years. The petrol consumption was estimated from the population approach for 1995 and used for the period 1990-99. Earlier years were extrapolated based on the building, contracting, mines, quarrying and water diesel consumption.
  - D. Domestic house & garden: Petrol and diesel oil consumption were estimated from the EMEP/CORINAIR population approach for 1995 and the same value used for all years.

- 3 The emission for each of the four main NAEI categories was estimated as:

$$E_p = e_p \cdot A_p$$

where

$$A_p = \text{Fuel consumption of NAEI main category } p \quad (\text{tonnes})$$

Emissions from off-road sources are particularly uncertain. The revisions in the population data produced higher fuel consumption estimates. The petrol consumption increased markedly but is still only a tiny proportion of total petrol sales. The aggregate emission factors calculated for each NAEI category are shown in Table 22 but show minor changes from the 1998 inventory.

Table 22 Aggregate Emission Factors for Off-Road Source Categories<sup>1</sup> (t/kt fuel)

| Source                   | Fuel    | C <sup>2</sup> | CH <sub>4</sub> | N <sub>2</sub> O | NO <sub>x</sub> | CO   | NM VOC | SO <sub>2</sub> <sup>3</sup> |
|--------------------------|---------|----------------|-----------------|------------------|-----------------|------|--------|------------------------------|
| Domestic House&Garden    | DERV    | 857            | 0.165           | 1.36             | 55.9            | 27.6 | 12.6   | 0.14                         |
| Domestic House&Garden    | Petrol  | 855            | 5.47            | 0.045            | 5.13            | 1330 | 413    | 0.473                        |
| Agricultural Power Units | Gas Oil | 857            | 0.167           | 1.34             | 54.9            | 17.1 | 7.71   | 2.8                          |
| Agricultural Power Units | Petrol  | 855            | 7.53            | 0.02             | 1.98            | 1367 | 753    | 0.473                        |
| Industrial Off-road      | Gas Oil | 857            | 0.169           | 1.36             | 44.3            | 16.6 | 6.26   | 2.8                          |
| Industrial Off-road      | Petrol  | 855            | 6.03            | 0.0672           | 8.15            | 2288 | 125    | 0.473                        |
| Aircraft Support         | Gas Oil | 857            | 0.164           | 1.37             | 53.3            | 12.4 | 5.47   | 2.8                          |

- 1 Emission factors reported are for 1999
- 2 Emission factor as kg carbon/t. UKPIA (1989)
- 3 UKPIA (2000). Factor for 1999

There is a small variation in emission factors from 1995 to 1999 since the new population data shows a change for certain items of machinery and also because it is assumed that the most recent sales of equipment complies with EU Stage 1 directives implemented in 1998. (Official Journal, 1998) However the effect of these variations on N<sub>2</sub>O and CH<sub>4</sub> factors are negligible.

The emission factors used for carbon dioxide were the standard emission factors for Derv, gas oil and petrol given in Table 1.

## 6 The IPCC Reference Approach

### 6.1 INTRODUCTION

The IPCC Reference Approach is a 'top down' inventory based on data on production, imports, exports and stock changes of crude oils, feedstocks, natural gas and solid fuels. Estimates are made of the carbon stored in manufactured products, the carbon consumed as international bunker fuels and the emissions from biomass combustion. The methodology followed is that outlined in IPCC (1997). However it was necessary to make a few adaptations to allow full use of UK energy and emission factor data, and these are described in subsequent sections. A complete set of IPCC Reference Approach worksheets are contained in the CRF, attached to this report on a CD ROM.



## 6.2 ACTIVITY DATA

The activity data are taken from DTI (2000) and is consistent with the categories listed in the IPCC Reference Approach. In order to improve the estimates, coal data were disaggregated into anthracite, coking coal and other bituminous coal, though for anthracite and coking coal, only imports, exports and consumption data were available.

The energy consumption in TJ (net) was calculated using gross calorific data for the fuels taken from DTI, (2000) and the conversion factors discussed in Section 3. Where suitable data were unavailable, defaults from IPCC (1997) were used. There have been some retrospective revisions in the calorific values used for coal based on DTI (2000). Also time series data for the GCV of fuels were used rather than an average figure for all years.

## 6.3 EMISSION FACTORS

Where possible, UK specific emission factors were used and are those given in this report. However in the case of solid and liquid fuels, these are expressed as t C/ t fuel and for gaseous fuels as g C/ therm (gross). Moreover, these factors already contain the correction for the fraction of carbon oxidised. Hence, in order to comply with the IPCC format, these factors were converted into base factors in terms of t C/ TJ (net) assuming complete oxidation. Since the oxidation fraction was not always known, the IPCC default values were assumed. Where UK emission factors were not available, IPCC defaults were used (IPCC, 1997).

## 6.4 CARBON STORED IN PRODUCTS

The carbon stored in products was calculated according to IPCC (1997b) using data from DTI (2000). Where possible UK estimates of the carbon fraction stored (Richardson, *et al* 1996) were used. The estimate of carbon stored from natural gas feedstock use was based on the capacity of methanol and acetic acid plants ( See Appendix 4). It is now assumed that 40% of lubricants are burnt as fuel, DTI (2000).

## 6.5 DISCREPANCIES BETWEEN THE IPCC REFERENCE AND 'BOTTOM-

The UKGHGI contains a number of sources not accounted for in the IPCC Reference Approach and so gives a higher estimate of CO<sub>2</sub> emissions. The unaccounted sources are:

- Land use change and forestry
  - Offshore flaring and well testing
  - Waste incineration
  - Non-Fuel industrial processes

In principal the IPCC Reference Total can be compared with the IPCC Table 1A Total plus the emissions arising from fuel consumption in 1B1 Solid Fuel Transformation and Table 2 Industrial Processes (Iron and Steel and Ammonia Production). The IPCC Reference totals are between 2-5 % higher than the comparable 'bottom up' totals. There are a number of reasons why the totals differ and these arise from differences in the methodologies and the statistics used.

These are:

1. The IPCC Reference Approach is based on statistics of production, imports, exports and stock changes of fuels whilst the 'bottom-up' approach uses fuel consumption data. The two sets of statistics can be related using mass balances (DTI, 2000), but these show that some fuel is unaccounted for. This fuel is reported under 'statistical differences' which consist of measurement errors and losses. A significant proportion of the discrepancy between the IPCC Reference approach and the 'bottom up' approach arises from these statistical differences particularly with liquid fuels.
2. The 'bottom up' approach only includes emissions from the non-energy use of fuel where they can be specifically identified and estimated such as with fertilizer production and iron and steel production. The IPCC Reference approach implicitly treats the non-energy use of fuel as if it were combustion. A correction is then applied by deducting an estimate of carbon stored from non-energy fuel use. The carbon stored is estimated from an approximate procedure which does not identify specific processes. The result is that the IPCC Reference approach is based on a higher estimate of non-energy use emissions than the 'bottom-up' approach.
3. The IPCC Reference Approach uses data on primary fuels such as crude oil and natural gas liquids which are then corrected for imports, exports and stock changes of secondary fuels. Thus the estimates obtained will be highly dependent on the default carbon contents used for the primary fuels. The 'bottom-up' approach is based wholly on the consumption of secondary fuels where the carbon contents are known with greater certainty. In particular the carbon contents of the primary liquid fuels are likely to vary more than those of secondary fuels.

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