Appendices

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Appendix 1
The UK Greenhouse Gas Inventory and the Emission Source Classification

CONTENTS

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_6)

Indirect Greenhouse Gases

- Nitrogen Oxides (as NO_2)
- 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 1990-2000 were submitted to UNFCCC in the Common Reporting Format (CRF). This is in accordance with a decision of the Conference of the Parties to the UNFCCC (FCCC/CP/1999/7). The CRF reports much more detail than the previously used 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 in this report, carbon dioxide emissions and removals are reported separately and that carbon dioxide removals are reported with a negative sign. However, in the CRF, carbon dioxide is reported as net emissions (=emissions +removals). This means that the totals reported for CO_2 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, 2001) 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 kerosene in the GHGI. However aviation turbine fuel includes fuel that is correctly described as jet gasoline using IPCC terminology. For non- CO_2 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 either coal or anthracite. 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, meat and bone meal, landfill gas and sewage gas. Some waste oils and scrap tyres are burnt in cement kilns. It is assumed that around 40% of lubricating oils are eventually burnt as fuel.

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

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

1 Includes fuel that is correctly termed jet gasoline.
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 or the new NRF system used for submission to CORINAIR.

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 Coke Production
1A1cii Other Energy Industries	Collieries Gas Production Gas Separation Plant (Combustion) Offshore Own Gas Use Production of Nuclear Fuel Town Gas Production
1A2a Iron and Steel	Iron and Steel (Combustion) Iron and Steel (Sinter Plant) Iron and Steel (Blast Furnaces)
1A2b Non-Ferrous Metals 1A2c Chemicals 1A2d Pulp, Paper and Print 1A2e Food Processing, Beverages, Tobacco	Included under Other Industry (Combustion)
1A2fi Other	Other Industry (Combustion) Cement (Fuel Combustion) Cement (Non-decarbonizing) Lime Production (Combustion) Autogenerators 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) Railways (Intercity) Railways (Regional)
1A3di International Marine	International Marine
1A3dii Internal Navigation	Coastal Shipping
1A3e Other Transport	Aircraft Support
1A4a Commercial/Institutional	Miscellaneous Public Services 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 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) SSF Production (Fugitive) 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 Onshore Loading
1B2 a Oil iv Refining/Storage	Refineries (drainage) Refineries (tankage) Refineries (Process) Oil Terminal Storage Petroleum Processes
1B2 a Oil vi Other	Not Estimated
1B2 a Oil v Distribution of oil products	Petrol Stations (Petrol Delivery) Petrol Stations (Vehicle Refuelling) Petrol Stations (Storage Tanks) Petrol Stations (Spillages) Petrol Terminals (Storage) Petrol Terminals (Tanker Loading) 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 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 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	Brick Manufacture (Fletton) Glass (continuous filament glass fibre) Glass (glass wool)
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 Chemical Industry Chemical Industry (Carbon Black) Chemical Industry (Ethylene) Chemical Industry (Methanol) Chemical Industry (Nitric Acid Use) Chemical Industry (Pigment Manufacture) Chemical Industry (Reforming) Chemical Industry (Sulphuric Acid Use) Coal, tar and bitumen processes Solvent and Oil recovery Ship purging
2C1 Iron and Steel	Iron and Steel (other) Iron and Steel (Basic Oxygen Furnace) Iron and Steel (Electric Arc Furnace) Iron and Steel Flaring (Blast Furnace Gas) 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 (other non-ferrous metals) Non-Ferrous Metals (primary lead/zinc) Non-Ferrous Metals (secondary Copper) Non-Ferrous Metals (secondary lead)
2D1 Pulp and Paper	Wood Products Manufacture
2D2 Food and Drink	Brewing (barley malting, fermentation, wort boiling) Bread Baking Cider Manufacture Other Food (animal feed; cakes, biscuits, cereals; coffee, malting, margarine and other solid fats; meat ,fish and poultry; sugar) Spirit Manufacture (barley malting, casking, distillation, fermentation, maturation, spent grain drying) Wine Manufacture
2E1 Halocarbon & SF6 By-Product Emissions 2E2 Halocarbon & SF6 Fugitive Emissions	Halocarbons Production (By-Product and Fugitive)
2E3 Halocarbon & SF6 Other	Not Estimated

2F1 Refrigeration & Air Conditioning	Refrigeration Supermarket Refrigeration Mobile Air Conditioning
2F2 Foam Blowing	Foams
2F3 Fire Extinguishers	Fire Fighting
2F2 Aerosols	Metered Dose Inhalers Aerosols(Halocarbons)
2F2 Solvents	Not Occurring
2F2 Other	Electronics Training Shoes 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) Decorative paint (trade decorative) Industrial Coatings (automotive) Industrial Coatings (agriculture & construction) Industrial Coatings (aircraft) Industrial Coatings (Drum) Industrial Coatings (coil coating) Industrial Coatings (commercial vehicles) Industrial Coatings (high performance) Industrial Coatings (marine) Industrial Coatings (metal and plastic) Industrial Coatings (metal packaging) Industrial Coatings (vehicle refinishing) Industrial Coatings (wood)
3B Degreasing & Dry Cleaning	Dry Cleaning Surface Cleaning Leather Degreasing
3C Chemical Products, Manufacture & Processing	Coating Manufacture (paint) Coating Manufacture (ink) Coating Manufacture (glue) Film Coating Leather coating Other Rubber Products Tyre Manufacture Textile Coating
3D Other	Aerosols (Car care, Cosmetics & toiletries, household products) Agrochemicals Use Industrial Adhesives Paper Coating Printing Other Solvent Use Non Aerosol Products (household, automotive, cosmetics & toiletries, domestic adhesives , paint thinner) Seed Oil Extraction 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 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 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 Laying Hens Wastes 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 4D 2 Agricultural Soils: Animal Emissions 4D 4 Agricultural Soils: Indirect Emissions	Agricultural Soils Fertiliser Agricultural Soils Crops
4E Prescribed Burning of Savannahs	Not Occurring
4F1 Field Burning of Agricultural Residues: Cereals	Barley Residue Wheat Residue Oats Residue
4F5 Field Burning of Agricultural Residues: 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[1]	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_2 Emissions and Removals from Soil	Agricultural Soils: Limestone Agricultural Soils: Dolomite
5E Other	Not estimated

1 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 6B2 Domestic and Commercial Wastewater 6B3 Other	Sewage Sludge Disposal
6C Waste Incineration	Incineration: MSW Incineration: Sewage Sludge Incineration: Clinical Incineration: Cremation
6D Other Waste	Not estimated
7 Other	Not estimated

4 References

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IPCC, (1997c), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC, (2000), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, ed. Penman, J, Kruger, D, Galbally, I, *et al*, IPCC National Greenhouse Gas Inventories Programme, Technical Support Programme Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

Appendix 2
Energy

CONTENTS

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 (e.g., power stations, cement kilns, coke ovens, 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, (2001). 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

E(p,s,f)	=	Emission of pollutant p from source s from fuel f	(kg)
A(s,f)	=	Consumption of fuel f by source s	(kg or kJ)

e(p,s,f) = Emission factor of pollutant p from source s from fuel f (kg/kg or kg/kJ)

The pollutants estimated in this way are:

- carbon dioxide as carbon
- NO_x 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/TJ gross 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 (2001) are reported in terms of energy content on a gross basis. In previous editions of this report emission factors for gases were reported as g/therm gross.

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. Advice from the petroleum industry suggests that propane and butane are the major constituents of LPG. The factor used is estimated based on an assumed 80%/20% mixture of propane and butane. This is broadly the proportion of the two gases produced.

DTI (2001) 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'.

As suggested in the IPCC Guidelines, carbon dioxide emissions from biomass combustion are not included in the National Total, 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 (2001) 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/meat and bone meal 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, 2001). Data collected from waste oil recyclers were 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 (2001) 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 (e.g. 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, 2001).

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. Hence autogenerators would be reported in the relevant sector where they can be identified e.g. iron and steel (combustion), refineries (combustion). However, in some cases the autogenerator cannot be identified from the energy statistics so it would be classified as other industry (combustion). This may mean that the split between iron and steel (combustion) and other industry (combustion) may be uncertain. 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[aj]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
ATF	Aircraft Military	859[a]	0.106[ad]	0.1[g]	8.5[ad]	8.2[ad]	0.994[ad]	0.72[z]
Burning Oil	Domestic	859[a]	0.309[b]	0.0265[g]	2.21[b]	0.16[f]	0.133[b]	0.42[z]
Burning Oil(P)	Domestic	859[a]	0.309[b]	0.0265[g]	2.21[b]	0.16[f]	0.133[b]	0.06[z]
Burning Oil	Other Sources	859[a]	0.0432[b]	0.0265[g]	2.84[m]	0.16[f]	0.0865[b]	0.42[z]
Gas Oil	Agriculture	857[a]	0.225[b]	0.026[g]	2.84[m]	0.71[f]	0.128[k]	2.8[z]
Gas Oil	Domestic	857[a]	0.303[b]	0.026[g]	2.16[b]	0.24[i]	0.13[b]	2.64[z]
Gas Oil	Fishing;Coastal Shipping, Naval; International Marine	857[a]	0.288[c]	0.2[t]	57[t]	7.4[t]	2.112[c]	19.4[h]
Gas Oil	Iron&Steel,Other Industry, Refineries	857[a]	0.0432[b]	0.026[g]	3.46[b]	0.24[i]	0.0865[b]	2.64[z]
Gas Oil	Public Service; Miscellaneous	857[a]	0.0432[b]	0.026[g]	2.84[b]	0.24[i]	0.0865[b]	2.64[z]
Fuel Oil	Agriculture; Public Service, Miscellaneous	850[a]	0.122[b]	0.0243[g]	6.99[m]	0.5[i]	0.122[b]	26.0[z]
Fuel Oil	Fishing;Coastal Shipping, International Marine	850[a]	0.288[c]	0.2[t]	57[t]	7.4[t]	2.11[c]	56.4[h]
Fuel Oil	Domestic	850[a]	0.303[b]	0.0243[g]	6.99[m]	0.5[i]	0.13[b]	26.0[z]
Fuel Oil	Iron&Steel,Other Industry, Railways (Stationary)	850[a]	0.122[b]	0.0243[g]	7.54[I]	0.5[i]	0.122[b]	26.0[z]
Fuel Oil	Refineries (Combustion)	850[a]	0.122[b]	0.0243[g]	4.11[z]	1.74[z]	0.122[b]	18.7[z]
Lubricants	Other Industry	804[g]	0.0432[e]	0.026[e]	3.46[e]	0.24[e]	0.0865[e]	2.8[e]
Naphtha	Refineries	940[a]	0.122[j]	0.0182[g]	7.54[j]	0.5[j]	0.122[j]	0.2[af]
Miscellaneous	Refineries	800[a]	0.122[j]	0.0247[g]	7.54[j]	0.5[j]	0.122[j]	0.2[af]
Petrol	Refineries	855[a]	0.0432[e]	0.0179[g]	3.46[e]	0.24[e]	0.0865[e]	0.22[z]

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

	C[aj]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Agriculture	659.6[n]	0.011[o]	0.155[w]	4.31[b]	4.1[i]	0.05[o]	21.0[aa]
Collieries	659.6[n]	0.011[o]	0.061[w]	4.53[b]	4.1[i]	0.05[o]	24.2[aa]
Domestic	676.8[n]	15.7[o]	0.119[w]	1.42[b]	45.0[f]	14[o]	20.3[aa]
Iron & Steel (Combustion)	659.6[n]	0.011[o]	0.0704[w]	4.97[b]	4.1[i]	0.05[o]	21.0[aa]
Miscellaneous, Public Service	659.6[n]	0.011[o]	0.143[w]	3.96[b]	4.1[i]	0.05[o]	21.0[aa]
Other Industry	659.6[n]	0.011[o]	0.213[w]	4.65[b]	4.1[i]	0.05[o]	21.0[aa]
Railways	659.6[n]	0.011[o]	0.0753[w]	5.04[b]	4.1[i]	0.05[o]	21.0[aa]
Autogenerators	659.6[n]	0.02[o]	0.0658[w]	4.65[b]	4.1[i]	0.03[o]	21.0[aa]

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

		C[aj]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Anthracite	Domestic	813.4[n]	2[o]	0.14[w]	1.6[b]	45[f]	1.7[o]	13.7[aa]
Coke	Agriculture	795.4[n]	0.011[p]	0.144[g]	4.0[b]	4.1[p]	0.05[p]	19[ab]
Coke	Coke Production; SSF Production	820[n]	0.011[p]	0.221[w]	4.8[b]	4.1[p]	0.05[p]	19[ab]
Coke	Domestic	803.6[n]	5.8[p]	0.111[w]	1.33[b]	45[q]	4.9[p]	16[ab]
Coke	I&S (Sinter Plant)	795.4[n]	0.011[p]	0.221[w]	10.9[b]	301[ae]	0.42[p]	12.4[ab]
Coke	I& S (Combustion) Other Industry	795.4[n]	0.011[p]	0.221[w]	4.8[b]	4.1[p]	0.05[p]	19[ab]
Coke	Railways	795.4[n]	0.011[p]	0.144[g]	4.8[b]	4.1[p]	0.05[p]	19[ab]
Coke	Miscellaneous; Public Service	795.4[n]	0.011[p]	0.144[g]	4.0[b]	4.1[p]	0.05[p]	19[ab]
MSW	Miscellaneous	75[ai]	0.0008[ai]	0.03[ai]	1.07[ai]	0.133[ai]	0.018[ai]	0.096[ai]
Petro-Coke	Refineries	800[a]	0.0156[p]	0.31[w]	8.26[z]	1.87[z]	0.071[p]	45.5[z]
SSF	Agriculture; Miscellaneous; Public Service	766.3[n]	0.011[p]	0.143[g]	3.96[b]	4.1[p]	0.05[p]	19[ab]
SSF	Domestic	774.2[n]	5.8[p]	0.112[w]	1.32[b]	45[q]	4.9[p]	16[ab]
SSF	Other Industry	766.3[n]	0.011[p]	0.218[w]	4.75[b]	4.1[p]	0.05[p]	19[ab]
Straw	Agriculture	418[g]	4.28[g]	0.057[g]	1.43[g]	71.3[g]	8.56[g]	0
Wood	Domestic	264[g]	3.61[b]	0.0388[g]	0.722[b]	99.3[g]	5.42[b]	0.037[m]
Wood	Other Industry	470[g]	0.482[b]	0.069[g]	3.21[b]	7.1[g]	0.803[b]	0.037[m]

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

Fuel	Source	C[aj]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Blast Furnace Gas	Coke Production	59460[n]	0.3[t]	2.0[ad]	104[t]	150[t]	3.0[t]	0
Blast Furnace Gas	Iron&Steel (Comb.), Blast Furnaces, Iron&Steel (Flaring)	59460[n]	112[t]	2.0[ad]	79.0[t]	39.5[t]	5.6[t]	0
Coke Oven Gas	Other Sources	15160[n]	7.5[b+]	1.8[ad]	81.0[b]	58.5[s]	17.5[b+]	210[v ah]
Coke Oven Gas	Blast Furnaces	15160[n]	7.5[b+]	1.8[ad]	606[v]	466[t]	17.5[b+]	210[v ah]
Coke Oven Gas	Coke Production	15160[n]	7.5[b+]	1.8[ad]	360[v]	466[t]	17.5[b+]	210[v ah]
LPG	Domestic	16230[ag]	0.92[m]	0.09[g]	46[b]	8.18[s]	1.84[m]	0
LPG	I&S, Other Industry, Refineries, Gas Production	16230[ag]	0.92[m]	0.09[g]	89.1[m]	2.37[s]	1.84[m]	0
Natural Gas	Agriculture, Miscellaneous, Public Service	14230[r]	3.6[b]	0.09[g]	46.2[m]	2.37[i]	3.6[b]	0
Natural Gas	Coke Production, SSF Prodn, Nuclear Fuel Prodn, Refineries, Blast Furnaces	14230[r]	3.6[b]	0.09[g]	90.0[b]	2.37[i]	3.6[b]	0
Natural Gas	Domestic	14230[r]	2.7[b]	0.09[g]	46.0[y]	8.18[f]	6.3[b]	0
Natural Gas	Collieries, Gas Prodn, Iron&Steel, Other Industry, Railways	14230[r]	3.6[b]	0.09[g]	46.0[y]	2.37[i]	3.6[b]	0
Natural Gas	Autogenerators	14230[r]	5.49[g]	3.33[g]	44.5[u]	0.18[ac]	4.83[l]	0
Natural Gas	Ammonia (Comb.)	14230[r]	3.6[b]	0.09[g]	163[d]	2.37[i]	3.6[b]	0
OPG	Gas production, Other Industry	15420[a]	3.07[b+]	NE	129[b]	2.37[s]	6.13[b+]	0
OPG	Refineries (Comb)	15420[s]	3.07[b+]	NE	86.8[z]	8.27[z]	6.13[b+]	0
Colliery Methane	All Sources	14230[s]	3.6[s]	0.09[g]	90[s]	2.37[s]	3.6[s]	0
Sewage Gas	Public Services	27400[g]	615[m]	0.09[g]	897[m]	165[m]	47.3[m]	0
Landfill Gas	Miscellaneous	27400[g]	615[m]	0.09[g]	897[m]	165[m]	47.3[m]	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 (2001), 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 (2001)
w	Fynes *et al* (1994)
x	as coke
y	British Gas (1994)
z	UKPIA (2001), Emission factor for 2000 derived from data supplied by UKPIA
aa	Emission factor for 2000 based on data provided by RJB(2001), Scottish Coal (2001), Celtic Energy (2001), Tower (2001), Betwys(2001)
ab	Munday (1990)
ac	Powergen (1994)
ad	EMEP/CORINAIR (1999)
ae	Factor derived from British Steel (2000) emissions data.
af	UKPIA (2001)
ag	LPG factor assumes an 80/20 mixture of propane/butane by weight.
ah	Emission factor based on data supplied by Corus (2001, 2000)
ai	See Table 6
aj	Emission factor as mass carbon per unit fuel consumption
NE	Not estimated.

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, (2001). 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 *et al*, 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. In 1999 and 2000, the fuel oil consumption reported by DUKES was been significantly lower than that estimated from returns from the power generators. In the inventory, the power generators figures are used otherwise the effective emission factors deduced from emissions data reported to the Environment Agency would be impossibly high. A correction is applied to other industry (combustion) so that total UK fuel oil consumption corresponds to that reported in DUKES. It is not clear why the discrepancy exists and this will be investigated.

Table 6: Emission Factors for Power Stations

	Unit	CO_2[1]	CH_4	N_2O	NO_X	CO	NMVOC	SO_2
Coal	kg/t	588.23[c]	0.02[s]	0.073[i]	6.29[j]	1.03[j]	0.0273[j]	17.46[j]
Fuel Oil	kg/t	850[a]	0.0054[p]	0.0243[d]	7.81[j]	1.45[j]	0.029[j]	33.7[j]
Orimulsion	kg/t	597.5[e]	0.0163[f]	0.017[f]	9.36[u]	1.39[u]	0.0437[u]	70.0[u]
Gas Oil	kg/t	857[a]	0.0432[b]	0.026[d]	2.75[j]	0.473[j]	0.0865[b]	3.25[j]
MSW	kg/t	75[l]	0.000797[r]	0.03[v]	1.07[t]	0.133[t]	0.018[t]	0.096[t]
Tyres	kg/t	757[o]	0.912[q]	0.0184[q]	NE	NE	NE	NE
Poultry Litter, meat and bone meal	kg/t	267[j]	0.436[q]	0.058[q]	1.11[j]	0.724[j]	0.033[j]	0.681[j]
Landfill/ Sewage Gas	g/GJ gr	27400[q]	615[h]	0.09[q]	897[h]	165[h]	47.3[h]	0
Sour Gas	g/GJ gr	18160[n]	0.216[m]	0.09[q]	199[j]	64[j]	0.486[j]	72.7[j]
Natural Gas	g/GJ gr	14230[g]	5.49[d]	3.33[k]	28.9[j]	4.5[j]	4.54[j]	0.442[j]

1 Emission factor as mass carbon/ 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 (Environmenr Agency, 2001), Environment Agency (2001a) 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 (2001)
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.

The emission factors used for Power Stations are shown in Table 6. The NO_x and SO_2 emissions from coal and oil stations are based on estimates for individual power stations released by the Environment Agency (2001a). 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. The CO and NMVOC emissions are reported in the Pollution Inventory (Environment Agency, 2001) on the same basis, hence a similar correction is made.

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 was 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_x, SO_2, NMVOC and CO were taken from Environment Agency (1998) but emission factors for methane and N_2O 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 which came into force at the end of 1996. Data are available (DTI, 2001) on the amount of waste used in heat and electricity generation and the emissions from the incinerators (Environment Agency, 2001). 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 and the heat component under miscellaneous. Since 1997, all MSW incinerators have generated electricity so the waste incineration category has reduced to zero.

In addition to MSW combustion, the inventory reports emissions from the combustion of scrap tyres 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 2000 the tyre burning plant closed down.

Also included are emissions from three plants which burnt poultry litter and wood chips. In 2000 one of these was converted to burn meat and bone meal. The carbon emissions are not included in the National Total since these derive from biomass but emissions are reported for information in the CRF. Emission factors are based on Environment Agency (2001) data and IPCC (1997) defaults for biomass. The fuel consumption is based on the operator's estimates. There is considerable variation in emission factors owing to the variability of the fuel.

Emission estimates were made from the generation of electricity from landfill gas and sewage gas (DTI, 2001). 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 duel-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 (2001) 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. The carbon emissions are not included in the National Total since these derive from biomass but emissions are reported for information in the CRF.

4.2 PETROLEUM REFINING

The NAEI category refinery (combustion) 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, 2001), 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, 2001) or IPCC (1997) defaults for oil. The NAEI definition of refinery (combustion) 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 refinery (combustion) 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 was removed in the 1999 Inventory.

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, (2001). 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 processes are blast furnaces and steel making, which are discussed here because they are included in the carbon balance. The process is:

I&S Blast Furnaces

coke → blast furnace gas + carbon sequestrated in pig iron + carbon emission

Steel Making

pig iron → carbon sequestrated in crude steel + carbon emission

Again by estimating the carbon content of the coke consumed, the blast furnace gas produced, the pig iron and the crude steel 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 (i.e. the carbon is sequestrated 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 (LTO). 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 (2001). 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 DTLR (2001b). This was used to estimate total domestic and international landing and take-offs (LTO).

(iii) Data on domestic aircraft km are reported by DTLR (2001b).

(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 (2001a) 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 DTLR (2001b) 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_2 [1]	SO_2
Aviation Turbine Fuel	859	0.72 [2]
Aviation Spirit	865	0.72 [2]

1 Emission factor as kg carbon/t.
2 UKPIA (2001). Factor for 2000

Table 8: Aircraft Movement Data

	1990	1991	1992	1993	1994	1995
Domestic LTOs(000s)	301	289	295	302	308	322
International LTOs (000s)	410	394	429	440	466	484
Domestic Aircraft Gm	92	92	98	101	103	109

	1996	1997	1998	1999	2000
Domestic LTOs(000s)	333	341	355	365	372
International LTOs (000s)	510	541	581	615	651
Domestic Aircraft Gm	114	119	125	127	129

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

Emissions from non-CO_2 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) (DLTR, 2001b) 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_2 Emission Factors for Aviation

	Units	CH_4	N_2O	NO_x	CO	NMVOC	Fuel
Domestic LTO	kg/LTO	0.394[a]	0.1[b]	9.0[a]	16.9[a]	3.706[a]	1000
International LTO	kg/LTO	6.96[a]	0.2[b]	23.6[a]	101.3[a]	65.54[a]	2400
Domestic Cruise	kg/t fuel	0[b]	0.1[b]	11[b]	7[b]	0.7[b]	-
International Cruise	kg/t fuel	0[b]	0.1[b]	17[b]	5[b]	2.7[b]	-

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 include 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 (2001). 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 (2001). 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_2O emissions are calculated based on fuel based emission factors using fuel consumption data from DTI (2001). 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, NMVOC, NO_x 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. There have been some minor changes to the intercity factors based on the advice that some of these train journeys use two locomotives.

Table 10: Railway Emission Factors (kt/Mt)

	C[1]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Freight	857	0.14	1.2	17.5	4.9	3.6	2.64
Intercity	857	0.14	1.2	26.6	7.8	3.7	2.64
Regional	857	0.045	1.2	40.5	8.9	1.2	2.64

1 Emission factor as ktonnes carbon per Mtonne fuel

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 in the 2000 inventory

The main changes made in compiling the 2000 inventory for road transport are in the use of revised vehicle emission factors for CH_4 and N_2O. The new factors from COPERT III

(European Environment Agency, 2000) provide more detail on the effects of speed or drive cycle on emissions of these pollutants from vehicles. Also, methane emission factors for modern Euro II and III vehicles were reduced from their Euro I levels according to reductions in total hydrocarbon emissions required to meet these tighter standards. A small change in the inventory also arises from a minor change in the historic UK vehicle kilometre data, based on a more detailed analysis of traffic data available for Northern Ireland

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 2000, 21.4 Mtonnes of petrol and 15.6 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 21.2 Mtonnes of petrol consumed by road vehicles in 2000. Around 93% of the petrol sold in the UK was unleaded.

Emissions of CO_2, expressed as kg carbon per tonne of fuel, are based on the H/C ratio of the fuel; emissions of SO_2 are based on the sulphur content of the fuel. Values of the fuel-based emission factors for CO_2 and SO_2 from consumption of petrol and diesel fuels are shown in Table 11. Values for SO_2 vary annually as the sulphur-content of fuels change and are shown in Table 11 for 2000 fuels based on data from UKPIA (2001).

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

	C[a]	SO_2[b]
Petrol	855	0.22
Diesel	857	0.08

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

b 2000 emission factor calculated from UKPIA (2001) figures on the weighted average sulphur-content of fuels delivered in the UK in 2000

Emissions of CO_2 and SO_2 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 2000 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_x, CO, CH_4 and N_2O are calculated from measured emission factors expressed in grammes per kilometre and road traffic statistics from the Department of Transport, Local Government and the Regions (DTLR, 2001a). 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 that 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

DTLR 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 (DTLR, 2001a). These estimates are based on traffic counts from the rotating census and core census surveys (DTLR, 2001b). Traffic data for Northern Ireland in 1999 and 2000 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 1998 levels by the same proportion as growth occurred in Great Britain. The 1998 vehicle kilometre data for Northern Ireland came from the Transportation Unit, Northern Ireland (Road Services, NI, 2001). Some changes were also made to the Northern Ireland vehicle kilometre data for earlier years based on a more detailed analysis of traffic data for these years from the Transportation Unit. The Northern Ireland data have been combined with the DTLR data for Great Britain to produce a time-series of total UK vehicle kilometres by vehicle and road type from 1970 to 2000.

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), DTLR (2001b)). 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 (DTLR, 2001b). 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 fleet composition: by age, technology and fuel type

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 catalysts, fuel injection systems and better engine management systems.

Table 14 shows the regulations which have come into force up to 2000 for each vehicle type. Some makes of car sold in the UK from 1998-2000 already meet the Euro III standard even though the standards for new registrations do not come into effect until 2001. The year 2000 also saw the introduction of emission standards for mopeds and motorcycles.

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 DTLR Vehicle Licensing Statistics. The Transport Statistics Bulletin “Vehicle Licensing Statistics: 2000 Data” (DTLR, 2001c) 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 Statistics: 2000” (DTLR, 2001c).

Year-of-first registration data for vehicles licensed in each year from 1990 to 2000 taken from DTLR's Vehicle Licensing Statistics reflect the age distribution of the fleet in these years.

Table 13 Average Traffic Speeds in Great Britain

URBAN ROADS		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

RURAL ROADS		Lights kph	Heavies kph
Rural single carriageway	Major roads Minor roads	80 67	75 63
Rural dual carriageway		113	89
Rural motorway		113	92

Table 14 Vehicle Types and Regulation Classes

Vehicle Type	**Fuel**	**Regulation**	**Approximate date into service in UK**
Cars	Petrol	Pre ECE-15.00 ECE-15.00 ECE-15.01 ECE-15.02 ECE-15.03 ECE-15.04 91/441/EEC (Euro I) 94/12/EC (Euro II) 98/69/EC (Euro III)	 1/1/1971 1/7/1975 1/7/1976 1/7/1979 1/7/1983 1/7/1992 1/1/1997 1/1/2001
	Diesel	Pre-Euro I 91/441/EEC (Euro I) 94/12/EC (Euro II) 98/69/EC (Euro III)	 1/1/1993 1/1/1997 1/1/2001
LGV	Petrol	Pre-Euro I 93/59/EEC (Euro I) Euro II	 1/7/1994 1/7/1997
	Diesel	Pre-Euro I 93/59/EEC (Euro I) Euro II	 1/7/1994 1/7/1997
HGV	Diesel (All types)	Old Pre-Euro I 91/542/EEC (Euro I) Euro II	 1/10/1988 1/10/1993 1/10/1996
Buses and coaches	Diesel	Old Pre-Euro I 91/542/EEC (Euro I) Euro II	 1/10/1988 1/10/1993 1/10/1996
Motorcycles	Petrol	Pre-2000: < 50cc, >50cc (2 st, 4st) 97/24/EC: all sizes	 1/1/2000

Statistics are also available on the number of new registrations in each year up to 2000, 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 2000 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 (DTLR, 2001d). 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 and 2000, but it was assumed that 5% of new car sales met Euro III standards in 1999 increasing to 10% in 2000. This was taken into account in the emission estimates for 2000.

Information from the bus industry suggested that around 5% of buses in 1997, 10% in 1998 and 15% in 1999 were fitted with oxidation catalysts to reduce emissions (LT Buses, 1998). A large proportion of buses was 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.

In January 2000, European Council Directive 98/70/EC came into effect relating to the quality of petrol and diesel fuels. This introduced tighter standards on a number of fuel properties affecting emissions. The principle changes in UK market fuels were the sulphur content and density of diesel and the sulphur and benzene content of petrol. The volatility of summer blends of petrol was also reduced affecting evaporative losses. During 2000, virtually all the diesel sold in the UK was of ultra-low sulphur grade (<50 ppmS), even this low level of sulphur content is not required by the Directive until 2005. Similarly, ultra-low sulphur petrol became on-line in filling stations in 2000, with around one-third of sales being of ULSP quality, the remainder being of the quality specified by the Directive. These factors and their effect on emissions were taken into account in the 2000 inventory. It is assumed that prior to 2000, only buses had made a significant switch to ULSD as this fuel was not widely available in UK filling stations.

Freight haulage operators are now looking at incentives to upgrade the engines in their HGVs or retrofit them with particle traps. DETR estimated that around 4000 HGVs and buses were retrofitted with particulate traps in 2000 (DETR, 2000). This was accounted for in the 2000 inventory.

Detailed information from DVLA was used on the composition of the motorcycle fleet in terms of engine capacity (DTLR, 2001c). 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_x, CO and NMVOCs used for the 2000 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 had not been any agreed factors reported for 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 17 to 21 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. Prior to 2000, 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. Motorcycles sold in 2000 were assumed to meet the Directive 97/24/EC and their emission factors were reduced according to the factors given in the latest version of COPERT III (European Environment Agency, 2000).

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 or particulate traps (CRTs) and the effectiveness of these measures in reducing emissions from the vehicles. The effectiveness of these measures in reducing emissions from a Euro II bus varies for each pollutant and is shown in Table 15. It is assumed that a bus fitted with an oxidation catalyst or CRT 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 or CRT

		NO_x	**CO**	**NMVOCs**
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
ULS diesel + CRT	Urban	0.90	0.17	0.19
	Rural	0.88	0.19	0.27

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).

Similarly, the small number of HGVs equipped with CRTs have their emissions reduced by the amounts shown in Table 16. Again these vehicles will also be running on ULS diesel.

Table 16 Scale Factors for Emissions from a Euro II HGV Running on Ultra-Low Sulphur Diesel and Fitted with a CRT

		NO_x	**CO**	**NMVOCs**
ULS diesel only	Urban	0.94	0.96	0.97
	Rural	0.99	1.01	1.02
ULS diesel + CRT	Urban	0.81	0.10	0.12
	Rural	0.85	0.10	0.12

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_x 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.

For the 2000 inventory, revisions were made to the emission factors used for methane and nitrous oxide. The new factors were taken from COPERT III (European Environment Agency, 2000) which provided more detail on the effects of speed or drive cycle on emissions of these pollutants, information that was previously unavailable. For N_2O, different factors are now used for petrol cars and LGVs with three-way catalyst (meeting Euro I standards and on) on urban, rural and highway roads. For CH_4, functions relating emission factor to average speed were used for light duty vehicles and for heavy duty vehicles, different factors were used for journeys on urban, rural and highway roads. COPERT III provides emission factors for vehicles only up to Euro I standards. For the more modern Euro II and Euro III vehicles now on the road, the CH_4 emission factors were reduced by the same ratio as the Euro I to Euro II and III reductions in the NMVOC emission factors. The uncertainties in these factors 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_2O 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:

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

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

The parameters β and e^{cold}/e^{hot} are both dependent on ambient temperature and β 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^{cold}/e^{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 Meteorological Office data for ambient temperatures over different parts of the UK.

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

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

where: l_{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 β of 0.23.

This methodology was used to estimate annual UK cold start emissions of NO_x, 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 22.

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 Meteorological Office temperature data for the UK, an average maximum daily temperature of 15^{o}C and an average daily diurnal rise in temperature of 9^{o}C was used. Petrol sold until 1995 had an RVP of around 98 kPa in winter blends and 87 kPa in summer blends (June - August). By 1998, the average volatility of summer blends had fallen to 76 kPa (Watson, 2001). It was assumed that in 2000, the volatility of summer blends was 70 kPa, the limit set by European Council Directive 98/70/EC for Member States with “arctic” summer conditions.

The equations specified in Table 22 give diurnal loss emissions in g/vehicle.day for uncontrolled ($DL_{uncontrolled}$) and canister controlled ($DL_{controlled}$) vehicles. Total annual diurnal losses were calculated from the equation:

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

where:

N = Number of petrol vehicles (cars and LGVs) in the UK parc
$F_{controlled}$ = 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 Meteorological Office temperature data for the UK, an annual mean temperature for the UK of 11^{o}C were used.

The equations specified in Table 22 give hot soak loss emissions in g/vehicle.trip for uncontrolled ($HS_{uncontrolled}$) and canister controlled ($HS_{controlled}$) vehicles. Total annual hot soak losses were calculated from the equation:

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

where:

VKM = total number of vehicle kilometres driven in the UK by the petrol vehicles (cars and LGVs)
l_{trip} = average trip length (8.4 km in the UK)
$F_{controlled}$ = 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 22 give running loss emissions in g/vehicle.km for uncontrolled ($RL_{uncontrolled}$) and canister controlled ($RL_{controlled}$) vehicles. Total annual running losses were calculated from the equation:

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

Table 17 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	0.137	0.080	0.138	0.129
	Euro II	0.096	0.056	0.097	0.090
	Euro III	0.067	0.039	0.068	0.063
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
	Euro III	0.029	0.014	0.007	0.007
Petrol LGVs	Pre-Euro I	1.708	0.771	1.137	1.054
	Euro I	0.085	0.087	0.186	0.175
	Euro II	0.060	0.061	0.130	0.123
Diesel LGV	Pre-Euro I	0.302	0.160	0.186	0.177
	Euro I	0.229	0.135	0.099	0.100
	Euro II	0.160	0.094	0.069	0.070
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
Pre-2000	>50cc 2st	9.52	8.28	8.34	8.29
	>50cc, 4st	1.83	1.27	1.28	1.26
Motorcycles	<50cc	2.71	4.07	5.76	5.62
97/24/EC	>50cc 2st	6.59	5.90	4.94	5.05
	>50cc, 4st	0.77	0.50	0.37	0.37

Table 18 NOx 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	0.286	0.313	0.596	0.562
	Euro II	0.143	0.157	0.298	0.281
	Euro III	0.086	0.094	0.179	0.169
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
	Euro III	0.192	0.109	0.145	0.138
Petrol LGVs	Pre-Euro I	1.83	2.28	3.25	3.16
	Euro I	0.329	0.392	0.630	0.605
	Euro II	0.164	0.196	0.315	0.303
Diesel LGV	Pre-Euro I	1.22	1.15	1.53	1.48
	Euro I	0.537	0.305	0.407	0.386
	Euro II	0.376	0.214	0.285	0.270
Rigid HGVs	Old	11.8	14.4	14.4	14.4
	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	18.2	24.1	24.1	19.8
	Pre-Euro I	16.9	12.9	11.7	11.5
	Euro I	9.14	6.82	5.98	5.86
	Euro II	7.48	5.58	4.89	4.79
Buses	Old	16.2	14.8	14.8	13.5
	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 Pre-2000	<50cc	0.030	0.030	0.030	0.030
	>50cc 2st	0.032	0.066	0.133	0.126
	>50cc, 4st	0.156	0.229	0.404	0.385
Motorcycles 97/24/EC	<50cc	0.010	0.010	0.010	0.010
	>50cc 2st	0.025	0.029	0.053	0.051
	>50cc, 4st	0.210	0.279	0.468	0.448

Table 19 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	1.26	1.10	3.89	3.56
	Euro III	1.13	0.99	3.50	3.20
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
	Euro III	0.166	0.095	0.122	0.116
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 Pre-2000	<50cc	23.8	36.5	52.1	50.8
	>50cc 2st	23.4	25.8	28.7	28.4
	>50cc, 4st	20.8	22.2	31.9	30.8
Motorcycles 97/24/EC	<50cc	2.4	3.6	5.2	5.1
	>50cc 2st	12.0	21.5	33.0	31.9
	>50cc, 4st	7.0	10.0	19.4	18.4

Table 20 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	0.085	0.026	0.043	0.039
	ECE 15.00	0.085	0.026	0.043	0.039
	ECE 15.01	0.085	0.026	0.043	0.039
	ECE 15.02	0.085	0.026	0.043	0.039
	ECE 15.03	0.085	0.026	0.043	0.039
	ECE 15.04	0.085	0.026	0.043	0.039
	Euro I	0.037	0.017	0.024	0.023
	Euro II	0.026	0.012	0.017	0.016
	Euro III	0.018	0.008	0.012	0.011
Diesel cars	Pre-Euro I	0.010	0.017	0.050	0.047
	Euro I	0.004	0.005	0.012	0.012
	Euro II	0.003	0.004	0.009	0.008
	Euro III	0.002	0.003	0.006	0.006
Petrol LGVs	Pre-Euro I	0.150	0.040	0.025	0.025
	Euro I	0.036	0.017	0.029	0.027
	Euro II	0.025	0.012	0.020	0.019
Diesel LGV	Pre-Euro I	0.005	0.005	0.005	0.005
	Euro I	0.004	0.004	0.004	0.004
	Euro II	0.003	0.003	0.003	0.003
Rigid HGVs	Old	0.418	0.100	0.091	0.091
	Pre-Euro I	0.120	0.045	0.039	0.039
	Euro I	0.071	0.022	0.017	0.016
	Euro II	0.066	0.020	0.015	0.015
Artic HGVs	Old	0.726	0.245	0.262	0.271
	Pre-Euro I	0.175	0.080	0.070	0.070
	Euro I	0.103	0.052	0.048	0.048
	Euro II	0.095	0.046	0.042	0.042
Buses	Old	0.525	0.390	0.363	0.324
	Pre-Euro I	0.175	0.080	0.070	0.070
	Euro I	0.173	0.097	0.073	0.071
	Euro II	0.162	0.084	0.064	0.062
Motorcycles Pre-2000	<50cc	0.219	0.219	0.219	0.219
	>50cc 2st	0.150	0.150	0.150	0.150
	>50cc, 4st	0.200	0.200	0.200	0.200
Motorcycles 97/24/EC	<50cc	0.048	0.048	0.048	0.048
	>50cc 2st	0.104	0.107	0.089	0.091
	>50cc, 4st	0.084	0.079	0.058	0.059

Table 21 N_2O 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	0.053	0.016	0.035	0.035
	Euro II	0.053	0.016	0.035	0.035
	Euro III	0.053	0.016	0.035	0.035
Diesel cars	Pre-Euro I	0.027	0.027	0.027	0.027
	Euro I	0.027	0.027	0.027	0.027
	Euro II	0.027	0.027	0.027	0.027
	Euro III	0.027	0.027	0.027	0.027
Petrol LGVs	Pre-Euro I	0.006	0.006	0.006	0.006
	Euro I	0.053	0.016	0.035	0.035
	Euro II	0.053	0.016	0.035	0.035
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
Rigid HGVs	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
Artic HGVs	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 Pre-2000	<50cc	0.001	0.001	0.001	0.001
	>50cc 2st	0.002	0.002	0.002	0.002
	>50cc, 4st	0.002	0.002	0.002	0.002
Motorcycles 97/24/EC	<50cc	0.001	0.001	0.001	0.001
	>50cc 2st	0.002	0.002	0.002	0.002
	>50cc, 4st	0.002	0.002	0.002	0.002

Table 22 Equations for diurnal, hot soak and running loss evaporative emissions from vehicles with and without control systems fitted

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

where:

T_{rise} = diurnal rise in temperature in °C
T_{max} = maximum daily temperature in °C
T_{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 (2001).

(ii) Naval fuel consumption is assumed to be marine diesel oil (MOD, 2001). 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. Also included in 1A4 are emissions from miscellaneous. This includes emissions from the commercial sector and some service industries.

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, 2001) 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^{-1})
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 were used to revise the PRI population/lifetime data for sources other than balers, combines, agricultural mowers, agricultural tractors, off-road trucks, forklifts, 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 1990-2000 for each of the four main categories

A. Agricultural power units: Data on gas oil consumption were taken from DTI (2001). The consumption of petrol was estimated using the population method for 1995 without correction. The same estimate was used for 1990 to 2000.

B. Aircraft support: Data on diesel oil consumption at Heathrow Airport were extrapolated on the basis of the number of takeoffs and landings (DTLR, 2001b; Leech, 1994)

C. Industrial off-road: The construction component of the gas oil consumption was calculated from DUKES data (DTI, 2001) on building and contracting; mines and quarrying and water giving a time series for 1990-2000. 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 1990-2000. 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:

$E_p = e_p \, . \, A_p$

where

A_p = Fuel consumption of NAEI main category p (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 23.

Table 23 Aggregate Emission Factors for Off-Road Source Categories[1] (t/kt fuel)

Source	Fuel	C[2]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2[3]
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	0.22
Agricultural Power Units	Gas Oil	857	0.166	1.34	54.6	17.1	7.68	18.7
Agricultural Power Units	Petrol	855	7.53	0.02	1.98	1367	753	0.22
Industrial Off-road	Gas Oil	857	0.171	1.38	44.0	16.7	6.31	2.64
Industrial Off-road	Petrol	855	6.03	0.0672	8.15	2288	125	0.22
Aircraft Support	Gas Oil	857	0.164	1.37	50.0	12.4	5.47	2.64

1 Emission factors reported are for 2000
2 Emission factor as kg carbon/t. UKPIA (1989)
3 UKPIA (2001). Factor for 2000

There is a small variation in emission factors from 1995 to 1999 since the new population data show 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_2O and CH_4 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 (2001) and are 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, (2001) and the conversion factors discussed in Section 3. Where suitable data were unavailable, defaults from IPCC (1997) were used. Time series data for the GCV of fuels were used rather than an average figure for all years. In the 2000 inventory the GCV used for petroleum coke has been revised based on data reported in DTI (2001). The same value is used for 1990-2000.

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 (2001). 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 (2001).

6.5 DISCREPANCIES BETWEEN THE IPCC REFERENCE AND 'BOTTOM-UP' INVENTORIES

The UKGHGI contains a number of sources not accounted for in the IPCC Reference Approach and so gives a higher estimate of CO_2 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, 2001), 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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