Appendix

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Appendix 1
The Methodology used for the UK Greenhouse Gas Inventory

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1   Introduction

The UK Greenhouse Gas Inventory (GHGI) is compiled to fulfil the UK's reporting obligations to UNFCCC and complies with the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997a, b, c). 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 which are discussed in detail in subsequent sections. 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 to the detailed sectoral Tier 2/3 methods in the IPCC Guidelines. This appendix describes the methodology used to make these estimates except for that of the industrial gases HFCs, PFCs and SF_6 which has been described by MCG (1999). Emissions of individual halocarbon species are not 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. The total global warming potential of the individual emissions is reported. 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. In addition, estimates are provided of carbon dioxide emissions using the simpler IPCC Reference Approach.

2   The Emission Source Classification

The NAEI 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. The fuels data are taken from the Digest of UK Energy Statistics (DUKES), (DTI, 1999) 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.

In addition to the detailed approach used to estimate the 10 pollutants, 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 2-4% higher than the 'bottom-up' approach. The IPCC Reference Total should be compared with the IPCC Table 1A Total plus certain emissions arising from fuel use in the fuel transformation, iron and steel and ammonia production categories emissions in IPCC Tables 1B and 2.

2.1   FUELS

IPCC Guidelines (IPCC, 1997a) give a list of fuels that should be considered when reporting emissions. Table A1 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. The NAEI reports emissions from aviation turbine fuel and these are mapped onto jet gasoline in the GHGI. However aviation turbine fuel includes fuel that is correctly described as jet kerosene using IPCC terminology. For non- CO_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 NAEI emissions to these categories it is assumed that only the coal used in coke ovens is coking coal; and the rest is reported as coal. Most of the coal used in the UK is bituminous coal; anthracite is reported separately.

(iii)   Coke Oven Coke. Gas works coke is no longer manufactured in the UK so all coke and coke breeze consumption is reported as coke oven coke.

(iv)   Colliery Methane. The IPCC Guidelines do not refer to colliery methane but significant use is made of it as a fuel in the UK so emissions are included in the GHGI.

(v)   Orimulsion. Orimulsion® is an emulsion of bitumen and water and was burnt in some power stations in the UK, however its use has now been discontinued

(vi)   Slurry. This is a slurry of coal and water used in some power stations.

(vii)   Sour Gas. Unrefined natural gas is used as a fuel on offshore platforms and in some power stations. It has a higher carbon and sulphur content than mains gas.

(viii)   Wastes used as fuel. The following wastes are used for power generation: municipal solid waste, scrap tyres, poultry litter, landfill gas and sewage gas. Some waste oils are burnt in cement kilns.

Table A1 Mapping of fuels used in the GHGI and the NAEI

	GHGI	NAEI
Category	Subcategory	Subcategory
Liquid	Motor Gasoline	Petrol
	Aviation Gasoline	Aviation Spirit
	Jet Gasoline	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	Poultry Litter
	Landfill Gas	Landfill Gas
	Sludge Gas	Sewage Gas

1   Includes fuel that is correctly termed jet kerosene.
2   Used in coke ovens.
3   Coal–water slurry used in some power stations
4   Unrefined natural gas used on offshore platforms and some power stations
5   Not referred to in IPCC Guidelines (IPCC, 1997a) but included in GHGI.

2.2   NAEI SOURCE CATEGORIES AND IPCC EQUIVALENTS

Tables A2 to A9 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 (only included in the NAEI)

All these differences are discussed in Section 3.

Tables A2 to A9 refer to NAEI base categories. Normally the NAEI is not reported in such a detailed form but in a summary UNECE/CORINAIR SNAP94, version 1.0, eleven sector format.

Table A2: 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
1A1ci Manufacture of Solid Fuels	SSF Production Coke Production
1A1cii Other Energy Industries	Collieries Gas Production 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 & Lime (Fuel 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 Road Transport: Petrol Evaporation
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 Other Non-Industrial 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 Fishing
1A4cii Agriculture/Forestry/Fishing (Fishing)	Fishing
1A5a Other: Stationary	No comparable category–included in 1A4a
1A5b Other: mobile	Aircraft Military Shipping Naval

Table A3: 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
1B2 a Oil ii Production	Petroleum Processes
1B2 b i Natural Gas. Production/Processing	
1B2 a Oil iii Transport	Offshore Loading
	Onshore Loading
1B2 a Oil iv Refining/Storage	Refineries (drainage)
	Refineries (process)
	Refineries (tankage)
	Oil Terminal Storage
1B2 a Oil vi Other	Not Estimated
1B2 ci Venting and Flaring: Oil	Refineries (Flares)
1B2 ciii Venting and Flaring: Combined	Offshore Flaring
1B2 a Oil v Distribution of oil products	Petrol Distribution Tankers
	Petrol Distribution (Retail Storage Stage 1)
	Petrol Distribution (Retail Storage Stage 2)
	Petrol Distribution (Refinery Dispatch)
	Petrol Distributions (Marketing Storage)
1B2 b ii Natural Gas. Transmission/Distribution	Gas Leakage
	Gasification Processes

Table A4: 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	Other Industry (Asphalt manufacture)
2A7 Other	
2B1 Ammonia Production	Ammonia Feedstock
2B2 Nitric Acid Production	Nitric Acid Production
2B3 Adipic Acid Production	Adipic Acid Production
2B4 Carbide Production	
2B5 Other	Sulphuric Acid Production Chemical Industry (Organic Chemicals)
2C1 Iron and Steel	Iron and Steel (non-combustion) 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	
2D1 Pulp and Paper	Not Estimated
2D2 Food and Drink	Brewing (barley malting, fermentation, wort boiling) Bread Baking Cider Manufacture Other Food (animal feed;cakes, biscuits, cereals; coffee, margarine and other solid fats; meat ,fish and poultry; sugar) Spirit Manufacture (barley malting, casking, distillation, fermentation, maturation, spent grain drying) Sugar Beet processing 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 A6: Mapping of IPCC Source Categories to NAEI Source Categories:
IPCC Table 3

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

Table A7: 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	Not Occurring
4B11 Liquid System	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 Agricultural Soils	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
5 Land Use Change & Forestry	Not Estimated

Table A8 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 CO2 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.

Table A9: 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: Industrial
6D Other Waste	Not estimated
7 Other	Not estimated

3 A Modular Structure for the Inventory

3.1 INTRODUCTION

The previous sections have 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 for each IPCC source category. Most correspond to source categories used in the NAEI although a few are sources added to ensure compliance with IPCC requirements. Thus the Inventory has been broken down into a number of modules, broadly in line with the IPCC source categories.

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 are calculated by applying an emission factor to an appropriate statistic. That is:

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

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:

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

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.

3.2 BASE 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, (1999). Emissions are calculated according to the equation:

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

where

$E(p,s,f)$ = Emission of pollutant p from source s from fuel f $\quad$ (kg)

A(s,f)   =   Consumption of fuel f by source s   (kg or therm)

e(p,s,f) =   Emission factor of pollutant p from source s from fuel f

                                                             (kg/kg or kg/therm)

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
- Other Non-Industrial
- Public Service
- Refineries
- Iron & Steel (Combustion)
- 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 Table A1, though not all fuels occur in all sources.

Tables A10, A11, A12 and A13 list the emission factors used in this module. Emission factors are expressed in terms of kg pollutant/ t for solid and liquid fuels and g/therm for gases. This differs from the IPCC approach which expresses emission factors as t pollutant/ TJ based on the *net calorific value* of the fuel. For gases the NAEI factors are based on the *gross calorific value* of the fuel. This approach is used because the gas consumption data in DTI, (1999) are reported in terms of energy content on a gross basis.

Carbon dioxide emissions from biomass combustion are not included in the national total as suggested in the IPCC Guidelines but emissions of other pollutants are. The NAEI includes emissions from the combustion of wood in the industrial and domestic sectors as well as the

combustion of straw in agriculture. DTI (1999) 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 A12. Emissions from biogas and poultry litter combustion are included in the GHGI and are discussed in Section 3.3.1 since they occur mainly in electricity generation.

For most of these categories, the emission is estimated from fuel consumption data reported in DTI (1999) 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 3.10
- Ammonia Feedstock (natural gas only):- See Section 3.12.7
- Ammonia (Combustion) (natural gas only):- See Section 3.12.7
- Cement & Lime Fuel (Combustion in cement and lime kilns) :- See Section 3.12.4

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. The fuel consumption of Other Industry is estimated so that the total fuel consumption of these sources Is consistent with DUKES (DTI, 1999).

Table A10: Emission Factors for the Combustion of Liquid Fuels (kg/t)

Fuel	Source	C	CH_4	N_2O	NO_x	CO	NMVOC	SO2
ATF	Aircraft Military	859[a]	0.0825[t]	0.1[g]	23.7[t]	4.0[t]	0.667[t]	1.0[z]
Burning Oil	Domestic	859[a]	0.309[b]	0.0265[g]	2.21[b]	0.16[f]	0.133[b]	0.6[z]
Burning Oil(P)	Domestic	859[a]	0.309[b]	0.0265[g]	2.21[b]	0.16[f]	0.133[b]	<0.1[z]
Burning Oil	Other Sources	859[a]	0.0432[b]	0.0265[g]	2.84[m]	0.16[f]	0.0865[b]	0.6[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]	2.8[z]
Gas Oil	Fishing;Coastal Shipping, Naval	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]	2.8[z]
Gas Oil	Other Non-Industrial	857[a]	0.0432[b]	0.026[g]	2.84[b]	0.24[i]	0.0865[b]	2.8[z]
Fuel Oil	Agriculture; Other Non-Industrial	850[a]	0.122[b]	0.0243[g]	6.99[m]	0.5[i]	0.122[b]	40.2[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]	40.2[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]	40.2[z]
Fuel Oil	Refineries	850[a]	0.122[b]	0.0243[g]	6.1[b]	0.5[i]	0.122[b]	40.2[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]	40.2[j]
Miscellaneous	Refineries	800[a]	0.122[j]	0.0247[g]	7.54[j]	0.5[j]	0.122[j]	40.2[j]
Petrol	Refineries	855[a]	0.0432[e]	0.0179[g]	3.46[e]	0.24[e]	0.0865[e]	0.8[z]

Table A11: Emission Factors for Combustion of Coal (kg/t)

	C	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]	21.8[aa]
Collieries	659.6[n]	0.011[o]	0.061[w]	4.53[b]	4.1[i]	0.05[o]	23.6[aa]
Domestic	676.8[n]	15.7[o]	0.119[w]	1.42[b]	45.0[f]	14[o]	19.0[aa]
Iron & Steel (Combustion)	659.6[n]	0.011[o]	0.0704[w]	4.97[b]	4.1[i]	0.05[o]	21.8[aa]
Miscellaneous, Public Service	659.6[n]	0.011[o]	0.143[w]	3.96[b]	4.1[i]	0.05[o]	21.8[aa]
Other Industry	659.6[n]	0.011[o]	0.213[w]	4.65[b]	4.1[i]	0.05[o]	21.8[aa]
Railways	659.6[n]	0.011[o]	0.0753[w]	5.04[b]	4.1[i]	0.05[o]	21.8[aa]
Autogenerators	659.6[n]	0.02[o]	0.0658[w]	4.65[b]	4.1[i]	0.03[o]	21.8[aa]

Table A12 Emission Factors for Combustion of Solid Fuels (kg/t)

		C	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]	14.4[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]	4.8[b]	109[ae]	0.05[p]	19[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]
Petro–Coke	Refineries	800[a]	0.0127[p]	0.256[w]	12.7[z]	4.1[p]	0.0577[p]	60.6[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	NE	4.28[g]	0.057[g]	1.43[g]	71.3[g]	8.56[g]	0
Wood	Domestic	NE	3.61[b]	0.0388[g]	0.722[b]	99.3[g]	5.42[b]	0.037[m]
Wood	Other Industry	NE	0.482[b]	0.069[g]	3.21[b]	7.1[g]	0.803[b]	0.037[m]

Table A13 Emission Factors for the Combustion of Gaseous Fuels (g/therm)

Fuel	Source	C	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Blast Furnace Gas	Coke Production	6273[n]	0.0317[t]	0.211[t]	11[t]	15.8[t]	0.317[t]	0
Blast Furnace Gas	Iron&Steel (Comb.), Blast Furnaces, Iron&Steel (Flaring)	6273[n]	11.8[t]	0.211[t]	8.33[t]	4.17[t]	0.591[t]	0
Coke Oven Gas	Other Sources	1599[n]	0.791[b+]	NE	8.55[b]	0.25[s]	1.85[b+]	53.8[v]
Coke Oven Gas	Blast Furnaces	1599[n]	0.791[b+]	NE	64[v]	49.2[t]	1.85[b+]	53.8[v]
Coke Oven Gas	Coke Production	1599[n]	0.791[b+]	NE	51.1[v]	49.2[t]	1.85[b+]	53.8[v]
LPG	Domestic	1874[a]	0.0971[m]	0.0095[g]	4.85[b]	0.863[s]	0.194[m]	0
LPG	I&S, Other Industry, Refineries, Gas Production	1874[a]	0.0971[m]	0.0095[g]	9.4[m]	0.25[s]	0.194[m]	0
Natural Gas	Agriculture, Miscellaneous, Public Service	1501[r]	0.38[b]	0.0095[g]	4.88[m]	0.25[i]	0.38[b]	0
Natural Gas	Coke Production, SSF Prodn, Nuclear Fuel Prodn, Refineries, Blast Furnaces	1501[r]	0.38[b]	0.0095[g]	9.5[b]	0.25[i]	0.38[b]	0
Natural Gas	Domestic	1501[r]	0.285[b]	0.0095[g]	4.85[y]	0.863[f]	0.665[b]	0
Natural Gas	Collieries, Gas Prodn, Iron&Steel, Other Industry, Railways	1501[r]	0.38[b]	0.0095[g]	9.5[b]	0.25[i]	0.38[b]	0
Natural Gas	Autogenerators	1501[r]	0.579[g]	0.351[g]	4.69[u]	0.019[ac]	0.51[l]	0
Natural Gas	Ammonia (Comb.)	1501[r]	0.38[b]	0.0095[g]	23.8[d]	0.25[i]	0.38[b]	0
OPG	All Sources	1627[a]	0.324[b+]	NE	13.6[b]	0.25[s]	0.647[b+]	0
Colliery Methane	All Sources	1501[s]	0.38[s]	0.0095[g]	9.5[s]	0.25[s]	0.38[s]	0
Sewage Gas	Public Services	NE	64.9[m]	NE	94.6[m]	17.4[m]	4.99[m]	0
Landfill Gas	Miscellaneous	NE	64.9[m]	NE	94.6[m]	17.4[m]	4.99[m]	0

Footnotes to Tables A10 to A13

a	UKPIA (1989)
b	CORINAIR (1992)
b+	Derived from CORINAIR(1992) assuming 30% of total VOC is methane
c	Methane factor estimated as 12% of total hydrocarbon emission factor taken from EMEP/CORINAIR(1996) based on speciation in IPCC (1997c).
d	Based on operators data : Terra Nitrogen(2000), Kemira(2000)
e	As gas oil
f	USEPA (1977)
g	IPCC (1997c)
h	EMEP (1990)
i	Walker *et al* (1985)
j	As fuel oil.
k	NMVOC emission factor estimated as 98.75% of total hydrocarbon emission factor taken from USEPA (1977).
l	USEPA(1997) estimated from total VOC factor and the methane factor given
m	USEPA(1997)
n	British Coal (1989)
o	Brain *et al,* (1994)
p	As coal
q	As anthracite
r	British Gas (1992)
s	As natural gas
t	EMEP/CORINAIR(1996)
u	Powergen (1997), National Power (1997)
v	Emission factor derived from emissions reported in the PI. Environment Agency (1999)
w	Fynes et al (1994)
x	as coke
y	British Gas (1994)
z	UKPIA (1999) Emission factor for 1998
aa	Emission factor for 1998 based on data provided by RJB(1999), Scottish Coal(1998), Celtic Energy (1999), Tower (1999)
ab	Munday (1990)
ac	Powergen (1994)
ae	Factor derived from British Steel (2000) emissions data.

3.2.2 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, (1999). The values used are averages over the period 1970-1998 reflecting the coverage of the NAEI. The values of the conversion factors used in the calculations are given in Table A14.

Table A14: Conversion Factors for Gross to Net Energy Consumption

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

The values given for solid, liquid and other gaseous fuels are taken from IPCC Guidelines (IPCC, 1997). The value used for LPG is based on the calorific value for butane, the major constituent of LPG (Perry, 1973). Blast furnace gas consists mainly of carbon monoxide and carbon dioxide. Since little hydrogen is present, the gross calorific value and the net calorific values will be the same.

3.3 ENERGY AND TRANSFORMATION INDUSTRIES

3.3.1 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 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.

Table A15: 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]	6.28[j]	1.26[j]	0.032[j]	22.0[j]
Fuel Oil	kg/t	850[a]	0.0054[p]	0.0243[d]	9.61[j]	0.72[j]	0.093[j]	55.2[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]	0.148[m]	2.1[t]	0.165[t]	0.0207[t]	0.061[t]
Tyres	kg/t	757[o]	0.912[q]	0.0184[q]	NE	NE	NE	NE
Poultry Litter	kg/t	NE	0.282[q]	0.0376[q]	1.06[j]	0.648[j]	0.152[j]	1.32[j]
Landfill/ Sewage Gas	g/therm	NE	64.9[h]	NE	94.6[h]	17.4[h]	4.99[h]	0
Sour Gas	g/therm	1916[n]	0.0228[m]	0.0095[q]	18.6[j]	12.0[m]	0.0912[j]	6.79[j]
Natural Gas	g/therm	1501[g]	0.579[d]	0.351[k]	4.01[j]	0.593[j]	0.488[j]	0.149[j]

1   Emission factor as kg carbon/ t unit fuel consumption
a   UKPIA (1989)
b   CORINAIR (1992)
c   British Coal (1989)
d   IPCC(1997)
e   BITOR(1995)
f   As fuel oil but adjusted on basis of gross calorific value
g   British Gas (1992)
h   USEPA(1997)
i   Fynes et al (1994)
j   Based on reported emissions data from PI (EA, 1999), Environment Agency (1999a) 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 (1999)
u   1997 factor reported in Goodwin et al (1999). Fuel no longer used.
NE   Not Estimated

The emission factors used for Power Stations are shown in Table A15. 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 (1999a). The Environment Agency emissions are reported on a power station basis so those from coal fired plant will include emissions from the fuel oil used to light up the boilers. A correction has been applied to the data so that the coal emissions reported in the NAEI pertain only to the coal burnt, and the oil emissions apply only to the oil burnt. This is necessary to fulfil IPCC and UNECE reporting requirements.

From 1991 to 1997 some UK power stations burnt orimulsion, an emulsion of bitumen and water. DTI (1998) gives the UK consumption of orimulsion. This fuel is only used by the electricity supply industry so these data were used in the category Power Stations. The carbon content of the fuel was taken from the manufacturers specification (BITOR, 1995). The emissions of NO_x, SO_2, NMVOC and CO were taken from Environment Agency (1999) 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 waste for some years now, though generation capacity has recently increased markedly owing to construction and upgrading of incinerators to meet new regulations by the end of 1996. Data have become available (DTI, 1999) on the amount of waste used in electricity generation and the emissions from the incinerators (Environment Agency, 1999). In previous inventories, these emissions were reported as waste disposal, but it is now possible to report the electricity generation component separately under Power Stations. Since 1997, all MSW incinerators have generated electricity so the waste incineration category has reduced to zero.

In addition to MSW combustion, the inventory now reports emissions from the combustion of scrap tyres and poultry litter to generate electricity. The tyre emissions are based on estimates compiled by DTI (2000) and a carbon emission factor based on the carbon content of tyres (Ogilvie, 1995). IPCC default factors based on oil are used. In the case of poultry litter, the carbon emission factor is zero and those for other pollutants are based on Environment Agency (1999) data and IPCC (1997) defaults for biomass. The consumption of poultry litter is based on the operator's estimates of plant capacity.

Emission estimates were made from the generation of electricity from landfill gas and sewage gas (DTI, 1999). 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 (1999) 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.

3.3.2 Petroleum Refining

The NAEI category Refineries is mapped onto the IPCC category 1A1b Petroleum Refining. The emission factors used are shown in Table A10. 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, 1999), the emissions are reported under 1A1b Petroleum Refining rather than as a fugitive emission under 1B2. Emission factors are either based on operators' data (Environment Agency, 1999) or IPCC (1997) defaults for oil. The NAEI definition of refinery aims to include all combustion sources and includes refinery fuels, electricity generation in refineries and fuel oils burnt in the petroleum industry.

3.3.3 Manufacture of Solid Fuels

3.3.3.1 Introduction

The mappings used for these categories are given in Table A2 and emission factors for energy consumption in these industries are given in Tables A10-A13. The fuel consumption for these categories are taken from DTI, (1999). The emissions from most sources are calculated as in the base combustion module. However the sources involving fuel transformation require a more complex treatment. The problem in estimating emissions from these sources is that fuels are manufactured from other fuels producing process emissions, and that subsequently the fuel is burnt elsewhere producing further emissions. Hence it is necessary to define a method of allocating the emissions to the various possible sources. 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 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 $\rightarrow$ coke +   coke oven gas +   carbon emission

Solid Smokeless Fuel Production

    coal/petro-coke $\rightarrow$ SSF +   carbon emission

Hence by estimating the carbon content of the fuel consumed in these processes and the carbon content of the coke, coke-oven gas and SSF produced, the carbon emission from each process

can be calculated. The other transformation process is blast furnaces, which is discussed here because it is included in the carbon balance. The process is:

I&S Blast Furnaces

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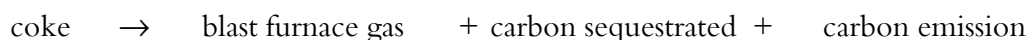
Again by estimating the carbon content of the coke consumed and the blast furnace gas produced, the carbon emission can be estimated.

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

In 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.

3.3.3.2 Coke Production

Applying the same nomenclature as that used in Section 3.2, the emission of carbon from coke production is:

$$E(car,coke\ prod,c) = A(coke\ prod,c) \times e(car,coke\ prod,c) - cout1$$

where

$$
\begin{aligned}
cout1 = \ & A(coke\ made,ck) \times e(car,coke\ made,ck) \\
& + E(car,coke\ prod,cog) \\
& + E(car,I\&S,\ cog) \\
& + E(car,I\&S\ BF,\ cog) \\
& + E(car,collieries,cog) \\
& + E(car,other\ industry,cog)
\end{aligned}
$$

and

A(coke made,ck)	=	Mass of coke made	(kg)
e(car,coke made,ck)	=	Carbon content of coke made	(kg/kg)
car	=	Carbon	
ck	=	Coke	
cog	=	Coke oven gas	
c	=	Coal	

The carbon contents of coking coal and coke made are 710 kg/t and 820 kg/t respectively.

For emissions of other pollutants, a mass balance approach is no longer used. It is now assumed that energy emissions arise from the combustion of the blast furnace gas and coke oven gas produced. The emission factors are given in Table A13. Process emissions from coke ovens are

estimated on the basis of total production of coke. The emission factors used are given in Table A16.

3.3.3.3 SSF Production

The emission of carbon from SSF production is:

$$
\begin{aligned}
E(car,ssf\ made,c) \ =\ & A(ssf\ prod,c) \times e(car,ssf\ prod,c) \\
& + A(ssf\ prod,pc) \times e(car,ssf\ prod,pc) \\
& + A(ssf\ prod,ck) \times e(car,ssf\ prod,ck) \\
& \quad - A(ssf\ made,ssf) \times e(car,ssf\ made,ssf)
\end{aligned}
$$

where

A(ssf made,ssf)	=	Mass of SSF made	(kg)
e(car,ssf made,ssf)	=	Carbon content of SSF made	(kg/kg)
ssf	=	Solid smokeless fuel	
pc	=	Petroleum coke	

The carbon contents of coking coal and coke made are 710 kg/t and 790 kg/t respectively. For emissions of other pollutants, a mass balance approach is no longer used. It is likely that emissions will arise from the combustion of the coke oven gas produced by some SSF retorts but this combustion is not identified in the energy statistics. Process emissions from SSF plant are estimated on the basis of total production of SSF. The emission factors used are given in Table A16 and are based on USEPA (1997) factors for different parts of the coke production process that are appropriate to the SSF processes used in the UK. Given that there are a number of processes in use these estimates will be very uncertain.

Data are available on the production of SSF and the fuels used (DTI, 1999), however it is clear that in recent years both coke and imported petroleum coke has been used in the production of smokeless fuels. Data on the total UK imports and exports of petroleum coke are available but little information is available on its consumption. In these estimates an assumption of an annual 100 kt usage in SSF production since 1992 is used based on DETR (1998f). The carbon emission from the coke and petroleum coke consumed is included in the process emission.

Emissions from the combustion of fuels to heat the smokeless fuel retorts are reported under 1A1ci Manufacture of Solid Fuels, however process emissions and the residual carbon emission discussed above are considered to be fugitives and are reported under 1B1b Solid Fuel Transformation.

Table A16 Emission Factors Used for Coke and Solid Smokeless Fuel Production (kt/Mt fuel produced)

	CH_4	CO	NO_x	SO_2	NMVOC
Coke	1.26[a]	4.6[b]	0.02[a]	0.01[a]	0.84[a]
SSF	0.45[a]	0.3[a]	0.005[a]	NE	0.3[a]

a   Emission factor derived from the Pollution Inventory (Environment Agency, 1999)
b   USEPA(1997)

3.3.3.4 Iron and Steel Blast Furnaces

The carbon emission from blast furnaces is calculated as:

$$E(car, I\&S\ BF, ck) = A(I\&S\ BF, ck) \times e(car, I\&S\ BF, ck)$$
$$- E(car, coke\ prod, bfg)$$
$$- E(car, I\&S, bfg)$$
$$- E(car, I\&S\ BF, bfg)$$
$$- E(car, flaring, bfg)$$
$$- A(I\&S\ BF, steel\ made) \times e(car, I\&S\ BF, steel\ made)$$

where

A(I&S B F,ck)	=	Blast furnaces coke consumption	(kg)
A(I&S BF,steel made)	=	Crude steel production	(kg)
e(car,I&S BF, steel made)	=	Carbon content of steel made	(kg/kg)
bfg	=	Blast Furnace Gas	

The final term in the equation is the carbon sequestrated in the steel produced. It is assumed that the carbon content of steel is around 1.7 kt C/Mt crude steel. This is a very approximate estimate but the carbon sequestrated is very small compared with the other terms.

For other pollutants the emissions are estimated based on the methodology described in IPCC (1997c) for blast furnace charging and pig iron tapping. The emission factors are expressed in terms of the emission per Mt of steel produced and are given in Table A17. Data on steel production are reported in ISSB(1999).

Emissions arising from the combustion of blast furnace gas and other fuels used for heating the blast furnace are reported under 1A2a Iron and Steel. Emissions from the process and the flaring of blast furnace gas are reported under 2C1 Iron and Steel Production. Emissions from blast furnaces currently include a contribution from non-ferrous metal processes. Carbon dioxide emissions from limestone and dolomite use in iron and steel production are reported under 2A3 Limestone and Dolomite use. In previous inventories they were reported under 2C1.

Table A17 Emission Factors for Blast Furnaces (kt/Mt Steel)

Pollutant	Blast Furnace Charging	Pig Iron Tapping	Total
NO_x	–	0.076	0.076
CO	1.33	0.112	1.442
NMVOC	0.1	0.02	0.12
SO_2	–	0.03	0.03

3.3.4 Other Energy Industries

Table A2 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 A10 to A14. 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.

3.4   AVIATION

The NAEI category Air Transport gives an estimate of emissions within a 1000 m ceiling of landing and takeoff. 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 (1999). This is the best approximation of aviation bunker fuel consumption available and is assumed to cover international, domestic and military use.

(ii)   Data on arrivals and departures of domestic aircraft at UK airports are reported by DETR (1999b). This was used to estimate total domestic and international landing and take-offs (LTO).

(iii)   Data on domestic aircraft km are reported by DETR (1999b).

(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 (1999a) 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 A18.

Table A18: Carbon Dioxide Emission Factors for Aviation (kg/t)

	CO_2[1]	SO_2
Aviation Turbine Fuel	859	1.0[2]
Aviation Spirit	865	1.0[2]

1   Emission factor as kg carbon/t.
2   UKPIA (1999). Factor for 1998

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) (DETR, 1999b) were used together with the default emission factors in Table A19 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 A19 together with the cruise fuel consumption.

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) defaults shown in Table A10

Table A19: 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)

3.5 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 (1999). Emission factors are reported in Tables A10 and A13.

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 (1999). 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 (1999). 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 A20 are aggregate factors so that all factors are reported on the common basis of fuel consumption.

Table A20: Railway Emission Factors (kt/Mt)

	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Freight	857	0.14	1.2	17.5	4.9	3.6	2.8
Intercity	857	0.14	1.2	27.8	8.2	3.7	2.8
Regional	857	0.045	1.2	40.5	8.9	1.2	2.8

3.6   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.

3.6.1 Improvements to the 1998 inventory

For the 1998 inventory, the main improvements made have been based on a closer examination of the available data on average vehicle speeds monitored on different types of roads and areas in the UK and reported in various DETR publications. This is important because average speed affects emission factors for road vehicles. Hence, the use of more detailed speed information has led to revisions in the average road-type emission factors for each vehicle class.

Improvements have also been made to the emission estimates for motorcycles, using more detailed information on the composition of the fleet and speed-related emission factors for each class of motorcycles. Account has also been taken of the increased use of ultra-low sulphur diesel in the bus fleet since 1997.

3.6.2 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 1998, 21.85 Mtonnes of petrol and 15.14 Mtonnes of diesel fuel (DERV) were consumed in the UK. It was estimated that of this around 0.7% of petrol was consumed by off-road vehicles and machinery, leaving 21.70 Mtonnes of petrol consumed by road vehicles in 1998. Around 79% 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 A21. Values for SO_2 vary annually as the sulphur-content of fuels change and are shown in Table A21 for 1998 fuels based on data from UKPIA (1999).

Table A21 Fuel-Based Emission Factors for Road Transport in kg/tonne fuel

	C^a	SO_2^b
Petrol	855	0.482
Diesel	857	0.8

a   Emission factor in kg carbon/tonne, based on UKPIA (1989)
b   1998 emission factor calculated from UKPIA (1999) figures on the weighted average
         sulphur-content of fuels delivered in the UK in 1998

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 1998 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 A22 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).

3.6.3 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 Environment, Transport and the Regions (DETR, 1999a). The emission factors are based on experimental measurements of emissions from in-service vehicles of different types driven under test cycles with different average speeds. The road traffic data used are vehicle kilometre estimates for the different vehicle types and different road classifications in the UK road network. These data have to be further broken down by composition of each vehicle fleet in terms of the fraction of diesel- and petrol-fuelled vehicles on the road and in terms of the fraction of vehicles on the road made to the different emission regulations which applied when the vehicle was first registered. These are related to the age profile of the vehicle parc.

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

3.6.3.1 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 A22 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	79.5	61.7	62.2	77.1
	ECE 15.00	68.3	50.8	49.4	62.8
	ECE 15.01	68.3	50.8	49.4	62.8
	ECE 15.02	63.0	49.7	50.0	64.9
	ECE 15.03	63.0	49.7	50.0	64.9
	ECE 15.04	55.9	44.4	47.0	58.2
	Stage I (91/441/EEC)	62.9	48.9	47.4	74.9
	Stage II	62.9	48.9	47.4	74.9
Diesel cars	Pre-Stage I	61.6	45.7	41.4	64.0
	Stage I	46.7	35.0	29.2	37.2
	Stage II	46.7	35.0	29.2	37.2
Petrol LGV	Pre-Stage 1	83.9	64.4	60.7	93.9
	Stage I	83.9	64.4	60.7	93.9
	Stage II	83.9	64.4	60.7	93.9
Diesel LGV	Pre-Stage 1	74.1	65.7	80.2	149
	Stage I	94.1	78.6	76.2	104
	Stage II	94.1	78.6	76.2	104
HGV rigid	Old	251	171	157	164
	Pre-Stage I	251	171	157	164
	Stage I	251	171	157	164
	Stage II	251	171	157	164
HGV artic	Old	502	371	345	297
	Pre-Stage I	502	371	345	297
	Stage I	502	371	345	297
	Stage II	502	371	345	297
Buses	Old	376	262	240	198
	Pre-Stage I	376	262	240	198
	Stage I	376	262	240	198
	Stage II	376	262	240	198
Motorcycles	< 50 cc	18	18	18	18
	> 50 cc, 2st	30	30	30	30
	> 50 cc, 4st	38	38	38	38

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.

3.6.3.1.1 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) $\leq$ 3.5 tonnes)
- Diesel Light Goods Vehicles (Gross Vehicle Weight (GVW) $\leq$ 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.

3.6.3.1.2 Vehicle kilometres by road type

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

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

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

These data have been combined with the DETR data for Great Britain to produce a time-series of total UK vehicle kilometres by vehicle and road type from 1970 to 1998.

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

3.6.3.1.3 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, 1999b). These data were rationalised with speed data from other DETR sources, including the 1997 National Road Traffic Forecasts (DETR, 1997) which give average speeds for different urban area sizes, and consolidated with average speed data for unconstrained rural roads and motorways published in Transport Statistics Great Britain (DETR, 1999b). They are shown in Table A23. 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.

3.6.3.1.4 Vehicle split by age and fuel type – fleet composition model

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

Table A24 shows the regulations which have come into force up to 1998 for each vehicle type.

The average age profile and the fraction of petrol and diesel cars and LGVs in the traffic flow each year are based on the composition of the UK vehicle fleet using DETR Vehicle Licensing Statistics. The Transport Statistics Bulletin "Vehicle Licensing Statistics: 1998" (DETR, 1999c) 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: 1998" (DETR, 1999c). For 1998, the fraction of diesel cars in the fleet was 11.1% while the fraction of diesel LGVs was estimated to be 69%.

Year-of-first registration data for vehicles licensed in each year from 1990 to 1998 taken from DETR's Vehicle Licensing Statistics reflect the age distribution of the fleet in these years.

Table A23 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 A23 Continued

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

Table A24 Vehicle Types and Regulation Classes

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

Statistics are also available on the number of new registrations in each year up to 1998, 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.

The available figures suggest that in 1998, 48% of the petrol car stock was fitted with three-way catalysts. 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. Taking account of the higher average annual mileage made by newer cars, it is estimated that 55% of the UK car kilometres in 1998 were made by cars fitted with functioning three-way catalysts.

The 1998 inventory took into account voluntary measures to reduce emissions from road vehicles. The Euro III emission standards for passenger cars (98/69/EC) come into effect from January 2001 (new registrations). However, some makes of cars sold in the UK already meet the Euro III standards (DETR, 1999d). Figures from the Society of Motor Manufacturers and Traders suggested that 3.7% of new cars sold in 1998 met Euro III standards (SMMT, 1999). This was taken into account in the emission estimates for 1998.

Information from the bus industry suggested that around 5% of buses in 1997 and 10% in 1998 were fitted with oxidation catalysts to reduce emissions (LT Buses, 1998). A large proportion of buses was run on ultra-low sulphur diesel in 1997 and 1998. 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 45% in 1998. These factors were taken into account in the 1998 inventory. Freight haulage operators are now looking at incentives to upgrade the engines in their HGVs or retrofit them with particle traps. However, the number of HGVs modified in this way is still very small so were not included in the inventory.

Detailed information from DVLA was used for the first time on the composition of the motorcycle fleet in terms of engine capacity (DETR, 1999c). 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

3.6.3.1.5 Hot emission factors

The emission factors for NOx, CO and NMVOCs used for the 1998 inventory are based on data from TRL (Hickman, 1998) and COPERT II, "*Computer Programme to Calculate Emissions from Road Transport*" produced by the European Topic Centre on Air Emissions for the European Environment Agency (1997). Both these sources provide emission functions and coefficients relating emission factor (in g/km) to average speed for each vehicle type and Euro emission standard derived by fitting experimental measurements to some polynomial functional form.

These functions were then used to calculate emission factor values for each vehicle type and Euro emission standard at each of the average speeds of the road and area types shown in Table A23. The calculated values were averaged to produce single emission factors for the four main

road classes described earlier (urban, rural single carriageway, rural dual carriageway and motorway), weighted by the estimated vehicle kilometres on each of the detailed road types taken from the 1997 NRTF (DETR, 1997).

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

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

For each type of vehicle, both TRL and COPERT II provide equations for different ranges of vehicle engine capacity or vehicle weight; emission factors calculated from these equations were therefore averaged, weighted according to the proportion of the different vehicle sizes in the UK fleet, to produce a single average emission factor for each vehicle type. These average emission factors are given in Tables A26 to A30 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 for the first time in the 1998 inventory. All motorcycles are assumed to be uncontrolled. It was also assumed that mopeds (<50cc) operate only in urban areas, while the only motorcycles on motorways are the type more than 50cc, 4-stroke. Otherwise, the number of vehicle kilometres driven on each road type were disaggregated by motorcycle type according to the proportions in the fleet.

Emissions from buses were scaled down according to the proportion running on ultra-low sulphur diesel fuel in each year, the proportion fitted with oxidation catalysts and the effectiveness of these measures in reducing emissions from the vehicles. The percentage effectiveness of these measures in reducing emissions from a Euro II vehicle varies for each pollutant and is shown in Table A25. It is assumed that a bus fitted with an oxidation catalyst is also running on ULS diesel.

Table A25 Scale Factors for Emissions from a Euro II Bus Running on Ultra-Low Sulphur Diesel and Fitted with an Oxidation Catalyst

		NOx	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

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

The older in-service vehicles in the test surveys that were manufactured to a particular emission standard would have covered a range of different ages. Therefore, an emission factor calculated for a particular emission standard (e.g. ECE 15.04) from the emission functions and coefficients from TRL and COPERT II is effectively an average value for vehicles of different ages which inherently takes account of possible degradation in emissions with vehicle age. However, for the more recent emission standards (Euro I and II), the vehicles would have been fairly new when the emissions were measured. Therefore, based on data from the European Auto-Oil study, the deterioration in emissions with age or mileage was taken into account for catalyst cars. It was assumed that emissions of CO and NOx increase by 60% over 80,000 km, while emissions of NMVOCs increase by 30% over the same mileage (DETR, 1996b). Based on the average annual mileage of cars, 80,000 km corresponds to a time period of 6.15 years.

Hot emission factors for methane and nitrous oxide were taken from estimates for European vehicles and emission control technologies published in the 1995 IPCC Guidelines for National Greenhouse Gas Inventories and are shown in Tables A29 and A30 (IPCC, 1995). Fewer measurements have been made on emissions of these pollutants from vehicles. Therefore, only average emission factors are used, covering all vehicle speed or road types. Their uncertainties can be expected to be quite large. However, the emission factors used reflect the fact that three-way catalysts are less efficient in removing methane from the exhausts than other hydrocarbons and also lead to higher N_2O emissions than non-catalyst vehicles.

3.6.3.2 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:

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

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 Met 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 NOx, 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).

It was estimated that cold-start emissions make up the following percentages of total road transport emissions in the UK in 1998:

NOx   6 %
CO   37 %
NMVOCs   20 %

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.

3.6.3.3 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 A31.

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

The equations specified in Table A31 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 Met Office temperature data for the UK, an annual mean temperature for the UK of 11°C was used.

The equations specified in Table A31 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:

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

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 A31 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:

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

It was estimated that evaporative emissions make up 25% of total road transport emissions of NMVOCs in the UK in 1998. Of these, 47% of the emissions were from diurnal losses, 50% were from hot soak losses and 3% from running losses.

Table A26 NMVOC Emission Factors for Road Transport (in g/km)

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

Table A27 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	0.29	0.31	0.60	0.56
	Euro II	0.143	0.157	0.298	0.281
Diesel cars	Pre-Euro I	0.623	0.570	0.739	0.718
	Euro I	0.392	0.223	0.296	0.282
	Euro II	0.274	0.156	0.207	0.197
Petrol LGVs	Pre-Euro I	1.83	2.28	3.25	3.16
	Euro I	0.33	0.39	0.63	0.61
	Euro II	0.16	0.20	0.32	0.30
Diesel LGV	Pre-Euro I	1.22	1.15	1.53	1.48
	Euro I	0.54	0.31	0.41	0.39
	Euro II	0.38	0.21	0.28	0.27
Rigid HGVs	Old	11.80	14.40	14.40	14.40
	Pre-Euro I	6.02	4.96	5.65	5.91
	Euro I	3.94	3.24	3.38	3.47
	Euro II	3.16	2.51	2.59	2.65
Artic HGVs	Old	18.20	24.10	24.10	19.80
	Pre-Euro I	16.93	12.93	11.69	11.52
	Euro I	9.14	6.82	5.98	5.86
	Euro II	7.48	5.58	4.89	4.79
Buses	Old	16.20	14.80	14.80	13.50
	Pre-Euro I	13.62	5.45	5.88	6.13
	Euro I	14.89	4.39	4.35	4.39
	Euro II	10.63	3.59	3.56	3.59
Motorcycles	<50cc	0.03	0.03	0.03	0.03
	>50cc 2st	0.03	0.07	0.13	0.13
	>50cc, 4st	0.16	0.23	0.40	0.39

Table A28 CO Emission Factors for Road Transport (in g/km)

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

Table A29 Methane Emission Factors for Road Transport (in g/km)

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

Table A30 N$_2$O Emission Factors for Road Transport (in g/km)

	Emission standard	Urban	Rural single c/way	Rural dual c/way	Motorway
Petrol cars	Pre- ECE	0.005	0.005	0.005	0.005
	ECE 15.00	0.005	0.005	0.005	0.005
	ECE 15.01	0.005	0.005	0.005	0.005
	ECE 15.02	0.005	0.005	0.005	0.005
	ECE 15.03	0.005	0.005	0.005	0.005
	ECE 15.04	0.005	0.005	0.005	0.005
	Stage I (91/441/EEC)	0.050	0.050	0.050	0.050
	Stage II	0.050	0.050	0.050	0.050
Diesel cars	Pre-Stage I	0.010	0.010	0.010	0.010
	Stage I	0.010	0.010	0.010	0.010
	Stage II	0.010	0.010	0.010	0.010
Petrol LGV	Pre-Stage 1	0.006	0.006	0.006	0.006
	Stage I	0.006	0.006	0.006	0.006
	Stage II	0.006	0.006	0.006	0.006
Diesel LGV	Pre-Stage 1	0.017	0.017	0.017	0.017
	Stage I	0.017	0.017	0.017	0.017
	Stage II	0.017	0.017	0.017	0.017
HGV rigid	Old	0.030	0.030	0.030	0.030
	Pre-Stage I	0.030	0.030	0.030	0.030
	Stage I	0.030	0.030	0.030	0.030
	Stage II	0.030	0.030	0.030	0.030
HGV artic	Old	0.030	0.030	0.030	0.030
	Pre-Stage I	0.030	0.030	0.030	0.030
	Stage I	0.030	0.030	0.030	0.030
	Stage II	0.030	0.030	0.030	0.030
Buses	Old	0.030	0.030	0.030	0.030
	Pre-Stage I	0.030	0.030	0.030	0.030
	Stage I	0.030	0.030	0.030	0.030
	Stage II	0.030	0.030	0.030	0.030
Motorcycles	< 50 cc	0.001	0.001	0.001	0.001
	> 50 cc, 2st	0.002	0.002	0.002	0.002
	> 50 cc, 4st	0.002	0.002	0.002	0.002

Table A31 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

3.7 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 A10.

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 (1999).

(ii)   Naval fuel consumption is assumed to be marine diesel oil (MOD, 1999). 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 A10

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

3.8 OTHER SECTORS COMBUSTION

The mapping of NAEI categories to 1A4 Other Sectors is shown in Table A2. The estimation procedure follows that of the base combustion module. The NAEI category Public Service is mapped onto 1A4a Commercial and Institutional. This contains emissions from stationary combustion at military installations which should be reported under 1A5a Stationary. Also included are stationary combustion emissions from the railway sector, including generating plant dedicated to railways.

Emissions from 1A4b Residential and 1A4c Agriculture/Forestry/Fishing are disaggregated into those arising from stationary combustion and those from off-road vehicles and other machinery. The estimation of emissions from off-road sources is discussed in Section 3.10. Emissions from fishing vessels are estimated from fuel consumption data (DTI, 1999) and emission factors are shown in Table A10.

3.9 OTHER COMBUSTION

Emissions from military aircraft and naval vessels are reported under 1A5b Mobile. The method of estimation is discussed in Sections 3.4 and 3.7 with emission factors given Tables A18, A19 and A10. 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 3.10

3.10 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 into the appropriate IPCC classes is shown in Table A2. 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 new 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:

$$E_j = N_j . H_j . P_j . L_j . (1 - Y_j . a_j). e_j$$

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	=	Average age of class j	(years)
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:

$$E_{vj} = N_j . H_j . e_{vj}$$

where

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

Population and age data were supplied by a market research telephone poll 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).

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 1990-1998 for each of the four main categories
      A.   Agricultural power units: These data were taken from DTI (1999)
      B.   Aircraft support: Data on diesel oil consumption at Heathrow Airport were extrapolated on the basis of the number of takeoffs and landings (DETR,1999b; Leech ,1994)
      C.   Industrial off-road: The construction component was calculated from DUKES data (DTI, 1999) on building and contracting; mines and quarrying and water. The industrial component was estimated from the population approach. This gave an estimate for 1995. This was extrapolated to earlier years using the DUKES data on building and contracting; mines and quarrying and water.
      D.   Domestic house & garden: This was 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 aggregate emission factors calculated for each NAEI category are shown in Table A32. The emission factors used for carbon dioxide were the standard emission factors for DERV, gas oil and petrol given in Table A10. There has been a significant revision in the estimates of fuel consumptions for the main categories since the 1996 Inventory. A recent study (PRI, 1998) focussed on four major categories: lawn mowers, portable generators, forklifts, cement mixers. As a result of this study more detailed estimates of population, engine type and annual usage were made. This resulted in reduced estimates of petrol consumption and consequent reductions in carbon monoxide, NMVOC and NO_x emissions.

Table A32 Aggregate Emission Factors for Off-Road Source Categories (t/kt fuel)

Source	Fuel	C[1]	CH$_4$	N$_2$O	NO$_x$	CO	NMVOC	SO$_2$[2]
Domestic House&Garden	DERV	857	0.157	1.32	54.2	26.4	12.1	0.8
Domestic House&Garden	Petrol	855	5.26	0.042	4.830	1230	415.7	0.48
Agricultural Power Units	Gas Oil	857	0.163	1.31	54.0	16.8	7.56	2.8
Agricultural Power Units	Petrol	855	7.53	0.02	1.98	1367	753	0.48
Industrial Off-road	Gas Oil	857	0.167	1.34	40.9	16.7	5.98	2.8
Industrial Off-road	Petrol	855	5.71	0.0702	8.50	2236	116	0.48
Aircraft Support	Gas Oil	857	0.164	1.37	56.5	12.4	5.49	2.8

1   Emission factor as kg carbon/t. UKPIA (1989)
2   UKPIA (1999). Factor for 1998

3.11   FUGITIVE EMISSIONS FROM FUELS

3.11.1 Coal Mining

The NAEI reports emissions of methane from coal mining in the categories Deep Mined Coal; Coal Storage and Transport; Open Cast Coal. These map onto the IPCC categories 1B1a Underground Mines-mining, 1B1ai Underground Mines-post-mining and 1B1a Surface Mines respectively. Emissions are calculated from coal production statistics reported in DTI, (1999). Data on the shallower licensed mines are not published and were supplied to us by Barty (1995) up to 1994. Licensed mines referred to privately owned mines and were generally smaller and shallower than the nationalised mines. Following privatisation, the distinction between licensed mines and deep mines no longer exists. For 1995, data from 1994 were used but in subsequent years the distinction has been abandoned. The emission factors used are shown in Table A33 and are taken from Bennett *et al* (1995).

Table A33 Methane Emission Factors for Coal Mining (kg/t coal)

	pre-1991	1991	1992	post-1992
Deep Mined Coal	10.1	10.3	11.1	9.17
Coal Storage & Transport	1.15	1.15	1.15	1.15
Licensed Mines	1.36	1.36	1.36	1.36
Open Cast Coal	0.34	0.34	0.34	0.34

The deep mine factors are aggregate factors for all British Coalmines and reflect the methane utilisation measures employed in the pits operating. For 1990-1993 the deep mined emission factor varies because the number of pits operating declined over the period. Pre-1991 emission factors are used for 1990 and post-1992 emission factors for 1993 onwards. In earlier inventories, emissions from the storage and transport of coal were aggregated with those from deep mined coal. Now they are split. The coal storage and transport factor is only applied to deep mined coal production. Since, the submission of the 1998 inventory, new data from the major coal producer have suggested that emission factors from current operating mines are

higher than those used in the 1998 inventory. Emissions from solid fuel transformation plants are negligible (Williams,1993)

3.11.2 Oil and Natural Gas

The estimates are based on the UKOOA sponsored SCOPEC Inventory (SCOPEC, 1999). This is a detailed inventory based on returns from the operating companies for the years 1995–1998. For years prior to 1995 the estimates are based on the UKOOA study for 1991 (UKOOA, 1993). This is the source that was used for previous inventories but was retrospectively revised by UKOOA to incorporate new data on flaring and loading emissions. (Russell, 1997). The emissions reported in these studies have been integrated into the NAEI and extrapolated to other years to produce a time series. The diesel oil consumption by offshore installations is not reported separately but is included under coastal shipping. In order to avoid double counts the UKOOA estimates have been corrected to remove diesel oil emissions.

In the NAEI, emissions from venting, well testing, fugitives are combined under the category offshore oil & gas. The other categories used are offshore flaring, offshore loading, onshore loading, oil terminal storage and offshore own gas use. The offshore emissions are estimated in the following categories, each with its own methodology.

3.11.2.1 Offshore Flaring
This includes flaring from offshore platforms and onshore terminals. Flaring emission data for CO_2, SO_2, NO_x, CO, NMVOC and methane were taken from the SCOPEC (1999) and UKOOA (1993) studies for 1995-1998 and 1991 respectively. These emissions were extrapolated to other years using the data on flaring volumes reported in DTI (1998). This involved calculating aggregate emission factors (kt pollutant /Mm^3 gas flared). The SCOPEC estimates were used for 1995-1998 and the UKOOA estimate for 1970-1994. The aggregate emission factors are given in Table A34 which shows factors for the most recent year and defaults for earlier years.

An additional estimate of nitrous oxide emissions from flaring is made based on a factor of 3.48 Gg/Tm^3 based in the IPCC (1997) default factor for natural gas. Flaring is reported under 1B2ciii Venting and Flaring – Combined, since many of the platforms produce both oil and gas. An estimate of NMVOC emissions from refinery flares is reported in 1B2ci Venting and Flaring: Oil and is based on a UKPIA (1998) estimate. This is based on UKPIA (1998) data for 1995-97. The 1998 estimate is derived from the Pollution Inventory (Environment Agency, 1999)

Table A34 Aggregate Emission Factors for Flaring, Fuel Gas Consumption and Well Testing.

		C	SO_2	NO_x	CO	NMVOC	CH_4
Flaring kt/Mm^3	1998	0.733	0.00038	0.00155	0.00822	0.00893	0.0107
	1970–94	0.716	0.00012	0.00135	0.00952	0.0102	0.0075
Fuel Gas kt/Mtherm	1998	2.01	0.00040	0.0176	0.00682	0.000218	0.0013
	1970–94	1.93	0.00039	0.0393	0.00699	0.000156	0.000972
Well Tests kt/Well Explored	1998	3.73	0.13	0.012	0.062	0.066	0.16
	1970–95	2.69	0.1	0.0087	0.045	0.076	0.12

3.11.2.2 Offshore Own Gas Use

This refers to the use of unrefined natural gas on offshore platforms and onshore terminals as a fuel in heaters, boilers, turbines and reciprocating engines. Gas combustion emission data for CO_2, SO_2, NO_x, CO, NMVOC and methane were taken from the SCOPEC (1999) and UKOOA (1993) studies for 1995-1998 and 1991 respectively. In the case of the UKOOA (1993) data it was necessary to apply a correction to remove the contribution from diesel oil consumption. This correction was based on the more detailed breakdown of emissions in the SCOPEC study and was necessary to avoid double counting with fuel oil consumption reported elsewhere in the inventory. These emissions were extrapolated to other years using the data on 'producers own use' reported in DTI (1999). The DUKES category 'producers own use' is mostly if not wholly natural gas used on offshore installations for running turbines, engines, heaters and boilers. This involved calculating aggregate emission factors (kt pollutant /Mtherm). The SCOPEC estimates were used for 1995-1998 and the UKOOA estimate for 1970-1994. The aggregate emission factors are given in Table A34. Emissions are reported under 1A1cii Other Energy Industries.

3.11.2.3 Well Testing

This activity involves the combustion of crude oil and crude gas that are not included in UK Energy Statistics. Combustion emission data for CO_2, SO_2, NO_x, CO, NMVOC and methane were taken from the SCOPEC (1999) and UKOOA (1993) studies for 1995-1998 and 1991 respectively. The estimates of the amounts of crude oil and gas burnt are fairly speculative. A correction was applied to the 1991 data to remove the contribution from diesel oil consumption in drilling in order to prevent double counting. Data from 1995-1998 and 1991 were extrapolated to other years using data on the numbers of wells explored, reported in DTI (1999a). Unfortunately the number of wells tested is only a small proportion of the number of wells explored and that proportion may vary from year to year. Also the number of wells explored varies considerably from year to year. Hence this method of extrapolation can only give a reflection of the well testing activity and is used because actual data on well testing are not collected. The SCOPEC estimate was used for 1995-1998 with the 1995 factor used for all previous years. The aggregate emission factors are given in Table A34. Well testing is reported under 1B2a Oil Production since many of the wells produce oil and gas.

3.11.2.4 Other Emissions from Platforms and Terminals

These include emissions of methane and NMVOC from platforms and terminals arising from cold venting and fugitive emissions and also NMVOC emissions from storage of crude oil at terminals. The approach adopted was determined by the data available. For the years 1995-1998, detailed estimates from the SCOPEC (1999) survey were used. For the year 1970-1992 estimates were extrapolated. This involved extrapolating the UKOOA (1993) estimates of total emissions (i.e. flaring, gas combustion, venting, fugitives and storage) using data on the numbers and type of platform or terminal. This involved calculating aggregate emission factors (kt pollutant/platform). The types of installation considered were oil platforms, gas platforms, oil/gas platforms, oil terminals and gas terminals. The platform data were taken from DTI (1997) and Oilfield Publications (1996).

The resulting emission estimates include flaring and gas consumption which have been estimated separately. In order to avoid double counting the flaring and gas consumption components estimated in 3.11.2.1 and 3.11.2.2 were subtracted. The emissions for the years 1993 and 1994 were then estimated by interpolation.

Table A35 Aggregate Emission Factors used for Emissions from Platforms, Terminals, Loading and Unloading

	Period	Units	CH$_4$	NMVOC
Gas Platforms	1970–92	kt/installation	0.589	0.0754
Oil Platforms	1970–92	kt/installation	0.327	0.393
Oil/Gas Platforms	1970–92	kt/installation	0.763	0.686
Gas Terminals	1970–92	kt/installation	3.0	0.425
Oil Terminals	1970–92	kt/installation	0.076	0.315
Offshore Loading	1970–96	t/kt oil	0.036	2
	1998	t/kt oil	0.043	1.44
Onshore Loading	1970–94	t/kt oil	0.018	1
	1998	t/ kt oil	0.013	0.94

3.11.2.5 Loading Emissions

Emissions from tanker loading and unloading were taken from the SCOPEC (1999) study for 1995-98. They are based on the tonnage of oil shipped and site specific emission factors, which account for recently applied abatement measures. Data for previous years were estimated in a similar manner using oil shipment data taken from DTI (1998, 1998a). These cover the amount of crude oil shipped by tanker from:

- production sites to UK users and export
- onshore terminals to UK users and export

It is assumed that no emission occurs from the amounts of crude oil transported by pipeline. The emission factors are taken from UKOOA (1995) and Russell (1997) and are shown in Table A35. The emission factors for 1998 are aggregate factors for all installations and include abatement measures and are based on SCOPEC (1999).

3.11.2.6 Leakage from the Gas Transmission System.

The NAEI category Gas Leakage covers emissions of methane and NMVOC from the UK Gas Transmission and Distribution System. This is mapped on to IPCC category 1B2b Natural Gas ii Transmission/Distribution. The estimates are derived from specific leak rates measured on the various types of gas mains and services together with data on the total lengths and types of the gas mains and services and their upgrading schedule (British Gas, 1993). The composition of natural gas is 91.6% w/w methane and 4.5% w/w NMVOC (British Gas, 1994) with the remainder being nitrogen and carbon dioxide. The carbon dioxide emission is not reported as it is negligibly small. In the 1998 inventory an extra emission of 40 kt methane has been included to account of high-pressure mains which were not included in the earlier study. (DETR, 1999)

3.11.2.7 Petrol Distribution

The NAEI categories Petrol Distribution cover evaporative emissions from the various stages distribution and sale of petrol from refinery dispatch to marketing storage. They are mapped onto 1B2a Distribution of Oil Products. The estimates are based on emission factors reported by Richards *et al*, (1984). A correction is applied to account for the decrease in volatility in petrol since 1988. For example, the aggregate factor for all petrol distribution in 1997 was 5 g

NMVOC/kg which is 91% of the uncorrected factor. The emission reported for refinery dispatch is based on UKPIA (1998) estimates and the Pollution Inventory (Environment Agency, 1999).

Table A36 Petrol Distribution Emission Factors (kt NMVOC/ Mt Petrol)

	Default	1998
Tankers	0.6	0.55
Retail Storage Stage 1	1.7	1.55
Retail Storage Stage 2	1.8	1.64
Marketing storage	1.4	1.27
Sum	5.5	5.01

3.11.2.8 Refineries

The IPCC category 1B2aiv Refining and Storage contains an estimate of NMVOC emissions from oil refineries. In the NAEI these are split into drainage, tankage and process emissions. All are based on UKPIA (1998) estimates and the Pollution Inventory (Environment Agency, 1999).

3.12 INDUSTRIAL PROCESSES

3.12.1 Cement Production

In a cement kiln, calcium carbonate ($CaCO_3$) is broken down to CaO and carbon dioxide. The emission was estimated from the annual UK production of clinker (DETR, 1999e) and an emission factor of 138.3 t/ kt clinker produced (IPCC, 1997). The clinker produced is then ground up with gypsum to produce cement. Since clinker may be imported or exported the production of cement is not precisely related to the production of clinker. Hence it is preferable to use clinker data to estimate carbon dioxide emissions.

3.12.2 Lime Production

Lime (CaO) is manufactured from limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) by heating in a lime kiln resulting in the evolution of carbon dioxide. UK limestone use is given in BGS (2000) and an emission factor of 120 t carbon/kt limestone was used based on the stoichiometry of the chemical reaction assuming pure limestone. For dolomite an emission factor of 130 t carbon /kt dolomite would be used, however dolomite calcination data are not given explicitly but included in the limestone data. Hence emissions will be under estimated. Dolomite calcination is believed to be a small proportion of the total hence the underestimate is unlikely to be significant. The limestone calcination data used exclude limestone calcined in the chemical industry since a large proportion of this is used in the production of sodium carbonate by the Solvay process. The limestone is calcined to produce carbon dioxide but nearly all this is recovered and is sequestrated in the sodium carbonate produced. Some of the subsequent uses of sodium carbonate result in the emission of CO_2 (e.g. glass manufacture and baking) but others do not (e.g. water softening). More data on sodium carbonate consumption by use are required before an estimate can be made. Hence the current estimate of lime calcination emissions are low.

3.12.3 Limestone and Dolomite Use

Emissions from the use of limestone and dolomite were estimated from the following sources:

- iron and steel manufacture
- glass manufacture
- agricultural soils (liming of soils)

Usage data are available in BGS (2000) and ISSB (1999) for iron and steel use. The emission factors were 120 t carbon/kt limestone or chalk and 130 t carbon /kt dolomite and assume all the carbon is released to atmosphere. The emissions from iron and steel use and glass are reported under 2A3 Limestone and Dolomite Use and those from soils under 5D CO_2 Emissions and Removals from Soils.

3.12.4 Cement and Lime Combustion Emissions

Sections 3.12.1 and 3.12.2 describe the emission of CO_2 from the degradation of limestone and dolomite used in cement and lime manufacture. The category cement & lime (fuel combustion) covers emissions of CO_2, methane and N_2O arising from the combustion of petroleum coke, coal, oil or natural gas in kilns. Emission factors are shown in Table 37a. In DUKES (DTI, 1999), this fuel consumption is included under 'industry'. Fuel estimates were for 1990–1993 (Blyth *et al*, 1996) and were extrapolated to other years by using clinker production data (DETR, 1999e) and limestone calcination data (BGS, 2000). Having estimated the consumption of coal, fuel oil and natural gas by the lime and cement sector, the fuel consumption by other industry was adjusted so that the total consumption agreed with DUKES (DTI, 1999). Estimates were also made of emissions from the combustion of scrap tyres and waste oils in cement kilns. The non-CO_2 factors for scrap tyres are the same as for coal, because this fuel is normally burnt mixed with a larger proportion of coal. The carbon content of scrap tyres was estimated from data in Ogilvie (1995). The fuel consumption was taken from Collingwood (1997) and DTI (2000).

For the pollutants NO_x, CO and SO_2, estimates were based on the emissions for these plant reported by the Environment Agency (1999). For earlier years these data were extrapolated on the basis of clinker production. The aggregate factors cover all fuels and those shown in Table A37b are for 1998. They are expressed in terms of the emission per tonne of clinker produced. The pollution inventory coverage of lime kilns is incomplete and not consistent, hence it was not possible to estimate this source.

Table A37a: Emission Factors for Cement and Lime Kilns based on Fuel Consumption

	CO_2	CH_4	N_2O	Units
Coal	659.6	0.3	0.1084	kt/Mt fuel
Fuel Oil	850	0.0406	NE	kt/Mt fuel
Natural Gas	1501	0.1045	NE	g/therm
Petro-Coke	800	0.346	0.1302	kt/Mt fuel
Scrap Tyres	757	0.0258	NE	kt/Mt fuel
Waste Oils	859	0.0406	NE	kt/Mt fuel

Table A37b: Emission Factors for Cement Kilns based on Clinker Production

|	CO	NO$_x$	NMVOC	SO$_2$	Units
Cement	1.4	4.13	0.0975	1.98	kt/Mt Clinker

3.12.5 Soda Ash Use

Emissions of CO_2 from soda ash (sodium carbonate) production are not specifically identified. However, the emissions arise from fuel combustion used in the Solvay process and should be included elsewhere under industrial combustion. Some of the uses of sodium carbonate produced result in the emission of CO_2 (e.g. glass manufacture, food and drink, pharmaceuticals) but others do not (e.g. water softening). Only the emission from soda ash used in glass production is reported in 2A4. This is based on estimates of the consumption of soda ash in the production of soda glass (British Glass, 1998). This is around 15% of the mass of glass produced. An emission factor of 113 kt C/ Mt soda ash is used. The estimates have been revised to include both container and flat glass.

3.12.6 Asphalt Consumption

The inventory reports emissions of NMVOCs from asphalt paving and road construction. The emission estimates are based on consumption data of bitumen emulsions, cut-back bitumen and cut-back fluxes. The emission factors used are 7, 87.5 and 700 kg/t for each component respectively. Data are provided by the Bitumen Association. Emissions from asphalt roofing are not reported due to lack of data.

3.12.7 The Feedstock Use of Natural Gas

Natural gas is used as a feedstock for the manufacture of ammonia (for fertilizer), methanol and acetic acid. The largest use is for ammonia manufacture by the steam reforming of natural gas to make hydrogen. The simplified reactions are:

$$CH_4 \quad + \quad H_2O \quad \Leftrightarrow \quad CO \quad + \quad 3H_2$$
$$CO \quad + \quad H_2O \quad \Leftrightarrow \quad CO_2 \quad + \quad H_2$$
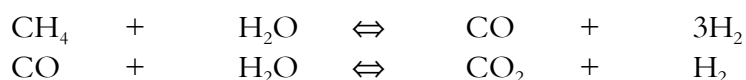
The hydrogen is then reacted with nitrogen from air to form ammonia

$$N_2 \quad + \quad 3H_2 \quad \Leftrightarrow \quad 2NH_3$$

If there is no use of the by-products CO and CO_2 formed then these are emitted to atmosphere. The carbon monoxide is usually oxidised so the CO_2 emission can be estimated from the natural gas usage or the amount of ammonia produced. The emission is 0.97 t CO_2 /t NH_3 produced based on the reaction stoichiometry.

In the UK some ammonia plants are integrated with methanol and acetic acid manufacture for greater efficiency. Thus hydrogen formed as a by-product from acetic acid manufacture is used as the feedstock for ammonia manufacture. Some carbon monoxide and carbon dioxide from the reforming process is used to manufacture methanol. This carbon is sequestrated as methanol and is not emitted to atmosphere.

Methanol is manufactured from natural gas using a process similar to ammonia

$$CO \quad + \quad 2H_2 \quad \Leftrightarrow \quad CH_3OH$$
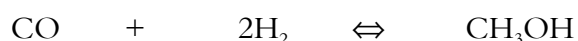
so that all the carbon content of the natural gas is sequestrated as methanol.

Acetic acid is manufactured from methanol and natural gas and again the carbon content of the natural gas is sequestrated.

Two estimates were made:

- The amount of CO_2 emitted from ammonia manufacture

- The amount of natural gas used in the manufacture of products. This can then be deducted from the total combustion of gas by industry in order to calculate the combustion emissions of the non- CO_2 pollutants.

The procedure adopted to estimate the emission of CO_2 from ammonia manufacture was:

1. Data on the plant capacity, natural gas consumption or CO_2 emission from
        ammonia plant
        acetic acid plant
        methanol plant
were collected from manufacturers. This included a breakdown between natural gas used as a feedstock and natural gas used as a fuel.

2. The ammonia capacity of the plants using hydrogen by-product from acetic acid manufacture was excluded.

3. Corrections were made based on manufacturers advice on the 'recovery ' of carbon in methanol manufacture.

The procedure used to estimate the natural gas use as a feedstock was to perform a carbon balance over the three processes:

1. Methanol plant capacity data were used to estimate its natural gas use

2. The natural gas usage of the acetic acid plant was available

3. The natural gas use equivalent to the CO_2 emission from ammonia manufacture was calculated

The total feedstock use of natural gas was estimated as the sum of items 1-3

The Inventory includes an estimate of the NO_x emission from the ammonia reformer reported under ammonia combustion. This arises from the combustion of natural gas to produce the high temperatures required by the process. The estimate was based on data provided by the manufacturers.
The necessary data were supplied by Terra Nitrogen, Kemira, ICI and BP Chemicals.

3.12.8 Nitric Acid Production

The manufacture of nitric acid produces emissions of both NO_x and nitrous oxide. In the NAEI, estimates of NO_x up to 1988 are estimated from the annual production of nitric acid

(CIS, 1991). The NO_x emission factor is 3.98 t/kt of 100% acid produced. This is an aggregate factor based on CORINAIR (1989) emission factors for the different types of processes ranging from 3-12 t/kt of 100% acid produced. The aggregate factor was based on data on UK Manufacturing plant provided by the Nitric Acid Association for the year 1985 (Munday, 1990).

UK production data have not been published since 1988. Since then a number of plants have either closed down, changed ownership, moved or have been fitted with abatement technology. For 1994 onwards estimates of NO_x are based on returns from manufacturers. Emissions from 1990 to 1993 were estimated by linear interpolation.

Certain plant were able to supply data on nitrous oxide emissions for 1998(Dupont, Kemira, Hydro Agri, Terra Nitrogen). For the remaining plant, the emissions were calculated from production data and application of a default emission factor of 6kt/Mt 100% acid produced. This is an average factor based the range quoted in IPCC Guidelines (IPCC, 1997) for medium pressure plant. For previous years, emissions were calculated for each plant by extrapolating the 1998 emission using production or plant capacity data. One plant currently has abatement measures so the uncontrolled default factor was used for the years prior to the retrofit. Up to 1988, the production data from (CIS, 1991) were used. Since 1994 production estimates based on returns from manufacturers were used. These are based mainly on plant capacity data which may over estimate true production levels. Production from 1989 to 1993 was estimated by linear interpolation.

3.12.9 Adipic Acid Production

Adipic acid is manufactured in a multi-stage process from cyclohexane via oxidation with nitric acid. Nitrous oxide is produced as a breakdown product from nitric acid. UK production figures and emission estimates have been provided by DuPont as the only company manufacturing adipic acid in the UK (DuPont, 1999). A small nitric acid plant is associated with the adipic acid plant which also emits nitrous oxide. From 1994 onwards this emission is reported as nitric acid but prior to 1994 it is included under adipic acid production. This allocation reflects the availability of data.

3.12.10 Other Chemical Industry

Emissions of sulphur dioxide are based on detailed manufacturers' returns compiled by NSSA (1999). Emissions of NMVOC, reported for the organic chemical industry are based on the Pollution Inventory (Environment Agency, 1999).

3.12.11 Iron and Steel

Emissions from limestone use in blast furnaces are reported under 2A3 (see Section 3.12.3). The following emissions are reported under 2C1 Iron and Steel Production.

- Iron and Steel Blast Furnaces: CO_2 and other process emissions (see Section 3.3.3)
- Flaring of blast furnace gas
- Electric arc furnaces
- Basic Oxygen Furnaces.

Electric arc furnaces are used in the production of stainless and mild steel and also for recycling scrap. Emissions are based mainly on default emission factors taken from the

UNECE/CORINAIR Draft Chapter on electric arc furnaces. The CO_2 emission arises from the consumption of a graphite anode and is based on manufacturer's data.

Large emissions of carbon monoxide have been reported by British Steel (2000). These were allocated to basic oxygen furnaces and sinter plant in proportion to the USEPA (1997) emission factors for uncontrolled plant. Sinter plant emissions are reported under 1A2a and emission factors are given Table A12.

Table A38: Emission Factors for Electric Arc and Basic Oxygen Furnaces

	CO_2 [a]	CH_4 [b]	N_2O [b]	NO_x [b]	SO_2 [b]	NMVOC[b]	CO[c]	Units
EAF	3.6	0.01	0.005	0.2	0.13	0.09	9	kt/Mt Steel
BOF	IE	NE	NE	NE	IE	NE	22[d]	kt/Mt Steel

a   BISPA (1997)
b   Berdowski *et al* (1997)
c   USEPA (1997)
d   Emission factor estimated to be consistent with British Steel (2000).

Emissions of NMVOC are estimated from the hot rolling and cold rolling of steel using emission factors 1 g/tonne product and 25 g/tonne product respectively (EMEP/CORINAIR, 1996). Activity data were taken from ISSB (1999).

There is insufficient activity data or emission factors to make an estimate for emissions from ferroalloys. Emissions of CO_2 will be included in Table 1A, since the fuels used as reducing agents are included in the energy statistics.

3.12.12 Aluminium Production

Aluminium is produced by the electrolytic reduction of alumina in large pots. During the reduction, the carbon anode is consumed resulting in the emission of CO_2, SO_2 and other pollutants. In the UK most aluminium is produced by the prebaked anode cell process, though one plant operates the older Soderberg Cell process. Emissions were estimated based on the production of aluminium for each type of process and the carbon emission factors shown in Table A39. The carbon emission factors reflect current practice, and higher emission factors were used for earlier years. For the other, pollutants the same factors were used for each process.

Table A39 Emission Factors for Aluminium Production (kt/Mt Al production)

	CO_2 [a]	SO_2 [b]	NO_x [b]	CO [a]
Soderberg	520	15.1	2.15	93
Prebake	420			

a CO_2 as carbon, Alcan (1997).
b   IPCC (1997c)

Emissions of PFCs from aluminium production are based on manufacturers' emission estimates (MCG, 1999).

3.12.13 Food and Drink

The NAEI reports emissions from the following food and drink processing activities. These are reported under 2D2 Food and Drink. Emission factors are listed below and are taken from EMEP/CORINAIR (1996). Activity data for food and drink were taken from ONS (1999) and data on whiskey production is taken from SWA (1999). Bread production data is based on estimates for 1988-1992 published in DTI (1992) which have been extrapolated to other years on the basis of population (ONS, 1999)

Table A40: NMVOC Emission Factors for Food and Drink Processing

Food/Drink	Process	Emission Factor	Units
Beer	Barley Malting	0.6	g/L beer
	Wort Processing	0.0048	
	Fermentation	0.02	
Cider	Fermentation	0.02	g/L cider
Wine	Fermentation	0.2	kg/m^3
Spirits	Fermentation	1.578	g/ L alcohol
	Distillation	0.789	g/ L alcohol
	Casking	0.395	g/ L alcohol
	Spent grain drying	1.31	kg/ t grain
	Barley Malting	4.8	kg/ t grain
	Maturation	15.78	g/ L alcohol
Bread Baking		3	kg/tonne
Meat, Fish & Poultry		0.3	kg/tonne
Sugar		10	kg/tonne
Margarine and solid cooking fat		10	kg/tonne
Cakes, biscuits, breakfast cereal, animal feed		1	kg/tonne
Coffee Roasting		0.55	kg/tonne

3.12.14 Halocarbons and SF$_6$ Production

Emissions of HFCs, PFCs and SF$_6$ from industrial processes are reported under 2E. The industrial processes considered are:

- Aluminium Production
- Magnesium Production
- Halocarbon Production

Here the halocarbon production refers to HFC, PFC and HCFC production. In the inventory it has been necessary to combine the by-product and fugitive emissions from HCFC for commercial reasons. The estimates and the methodology used in the estimation of these emissions are described in MCG (1999). Speciated emissions are not reported for the reasons given in Section 3.12.15.

3.12.15 Consumption of Halocarbons and SF$_6$

Emissions of HFCs, PFCs and SF$_6$ from various uses of these products are reported under 2F. The uses considered are:

- Refrigeration (Domestic, Industrial, Retailing)
- Air Conditioning (Mobile and Stationary)
- Foam Blowing
- Firefighting (Static Systems and Portable)
- Metered Dose Inhalers
- General Aerosols
- Electronics
- Training Shoes
- Electrical Insulation

The category electronics refers to a range of specialist uses of PFCs and SF_6 in the electronics industries. Some of the PFC is used for precision cleaning, however this is not reported as solvent use. No emission is reported under 2F2 Solvent because there is no use of halocarbons for dry cleaning. Training shoes refers to the leakage of PFC and SF_6 used in the soles of some training shoes. Electrical insulation is the leakage of SF_6 from circuit breakers. The estimates and the methodology used in their estimation are described in MCG (1999).

The approach adopted was to estimate the consumption and emissions of the fluids used in the above list of sectors however with a more detailed breakdown into types of refrigeration equipment and foam. Data are available on the speciation of the fluids used in these applications, hence estimates were made of the global warming potential of each fluid category. It is not possible to report emissions by PFC or HFC species as much of the data was obtained from private companies on condition it was confidential. However, estimates of the total GWP of emissions in the main IPCC categories are provided.

3.12.16 Potential Emissions of Halocarbons and SF_6

Potential emissions are in effect the apparent consumption of a fluid in a particular year. The IPCC (1997c) Tier 1 methodology defines a mass balance on the production, imports, exports and disposal of a fluid on a national basis. A further refinement is to include the total fluid exported and imported in products e.g. refrigerators and aerosol cans. Potential emissions differ from actual emissions in that no account is made of the fluid that is stored in products and is emitted over a long period of time.

In this work, potential emissions were estimated from the same data used to calculate the actual emissions (MCG, 1999). This was the annual consumption of fluid by each product sector and the amounts imported and exported into each product sector. Thus it was possible to estimate the annual amount of fluid consumed by each product sector and process that contributes to emissions. Hence, it was possible to report a potential emission for each product sector and process in Sectoral Table 2. The sum of the emissions from each sector and process is the total potential emission. It should be noted that this procedure differs from the Guidelines Tier 1 calculations, but the resulting potential emission is consistent with the definition in the IPCC 1996 Guidelines (1997c). The reporting of potential emissions is inapplicable to halocarbon manufacture and aluminium production though they were estimated for SF_6 cover gas use during the manufacture of magnesium.

It is not possible to report potential emissions by PFC or HFC species as much of the data was obtained from private companies on condition it was confidential. However, estimates of the total GWP of potential emissions in the main IPCC categories are reported.

3.13   SOLVENT AND OTHER PRODUCT USE

Table A2 shows the NAEI Solvent Use categories that map onto the IPCC category 3 Solvent and Other Product Use. The estimates are based on data on solvent use in the sectors supplied by trade associations and manufacturers. The time series is then estimated on the basis of production statistics of the various products. The methodology is described in Passant *et al* (1998).

An estimate is included of the carbon dioxide equivalent of the solvent consumption. This estimate is based on applying speciation data (Rudd, 1995) to the solvent emissions and calculating their total carbon content. A factor of 0.702 kg C/kg CO_2 was estimated based on 1996 data and applied to all years. The CO_2 estimate is included as a footnote to Table 3 and is not included in the National Total.

3.14   AGRICULTURAL EMISSIONS

3.14.1 Livestock

The NAEI estimates emissions of methane from farm animals resulting from enteric fermentation and the storage and disposal of animal wastes. The methane emission estimates were supplied by MAFF (2000a).

3.14.1.1 Enteric Emissions of Methane

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms. Emissions are calculated from animal population data collected in the June Agricultural census and published in MAFF (1999b) and the appropriate emission factors. Earlier years data are often revised so data were taken from the MAFF database. Table A41 shows the emission factors used. Apart from cattle, lambs and deer, the methane emission factors are IPCC defaults (IPCC, 1997) and do not change from year to year. The dairy cattle emission factors are estimated following the IPCC Tier 2 procedure (IPCC, 1997) and vary from year to year. For dairy cattle, the calculations are based on the population of the 'dairy breeding herd' rather than 'dairy cattle in milk' used in earlier inventories. This definition includes 'cows in calf but not in milk'. The emission factors for beef and other cattle were also calculated using the IPCC Tier 2 procedure, but do not vary from year to year. The factors for beef cattle were almost identical to the IPCC defaults so the default was used in the estimates. The base data and emission factors for 1990–1998 are given in Tables A42 and A43. The emission factor for lambs is assumed to be 40% of that for adult sheep. In using the animal population data it is assumed that the reported number of animals are alive for that whole year. The exception is the treatment of sheep where it is normal practice to slaughter lambs and other non-breeding sheep after 6 to 9 months. Hence it is assumed that breeding sheep are alive the whole year but that lambs and other non-breeding sheep are only alive 6 months of a given year. The sheep emission factors in Table A41 are reported on the basis that the animals are alive the whole year.

Table A41 Methane Emission Factors for Livestock Emissions.

	Enteric Methane[a] kg CH_4/head/year	Methane from Wastes[a] kg CH_4/head/year
Dairy Breeding Herd	114[b]	12.9[b]
Beef Herd	48	2.74
Others>1, Dairy Heiffers	48	6
Others<1	32.8	2.96
Pigs	1.5	3
Breeding Sheep	8	0.19
Other Sheep	8[e]	0.19[e]
Lambs < 1year	3.2[ce]	0.076[ce]
Goats	5	0.12
Horses	18	1.4
Deer (stags & hinds)	10.4[c]	0.26[c]
Deer (calves)	5.2[c]	0.13[c]
Poultry[d]	0	0.078

a   IPCC(1997)
b   Emission Factor for year 1998
c   Sneath *et al* (1997)
d   Chickens, turkeys, geese, ducks and guinea fowl.
e   Factor quoted assumes animal lives for a year. Emission calculation assumes animal lives for 6 months.

Table A42 Dairy Cattle Methane Emission Factors[1]

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Average Weight of cow (kg)[2]	550	556	561	567	572	578	584	590	596
Average Rate of Milk Production (litre/d)	14.3	14.2	14.5	14.7	14.7	15.0	15.1	15.9	16.1
Average Fat Content (%)	4.01	4.04	4.06	4.07	4.05	4.05	4.08	4.07	4.07
Enteric Emission Factor (kg CH_4/head/y)	104	104	106	107	107	109	110	113	114
Manure Emission Factor (kg CH_4/head/y)	11.7	11.7	12.0	12.1	12.1	12.3	12.4	12.7	12.9

1   43% of animals graze on good quality pasture, rest confined
     Gestation period 281 days
     Digestible Energy 65%
     Methane conversion rate 6%
     Ash content of manure 8%
     Methane Producing Capacity of Manure 0.24 m³/kg VS
2   Weight assuming annual growth of 1% from 1990.

Table A43 Beef and Other Cattle Methane Emission Factors[1]

	Beef Cattle	Other Cattle
Average Weight of Animal (kg)	500	180
Time Spent Grazing	50%	46%
GE (MJ/d)	123.3	83.4
Enteric Emission Factor (kg CH_4/head/y)	48.5[2]	32.8
Manure Emission Factor (kg CH_4/head/y)	2.74	2.96

1   Digestible Energy 65%
     Ash content of manure 8%
     Methane producing capacity of manure 0.24 m³/kg VS
2   IPCC (1997) default (48 kg/head/y) used since calculated factor is very close to default

3.14.1.2 Methane Emissions from Animal Wastes.

Methane is produced from the decomposition of manure under anaerobic conditions. When manure is stored or treated as a liquid in a lagoon, pond or tank it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. Hence the system of manure management used affects emission rates. Emissions of methane from animal wastes are calculated from animal population data (MAFF, 1999b) in the same way as the enteric emissions. The emission factors are listed in Table A41. Apart from cattle, lambs and deer, these are all IPCC defaults (IPCC, 1997) and do not change from year to year. The emission factors for lambs are assumed to be 40% of that for adult sheep. Emission factors for dairy cattle were calculated from the IPCC Tier 2 procedure using data shown in Tables A42 and A44 (MAFF, 2000a). For dairy cattle, the calculations are based on the population of the 'dairy breeding herd' rather than 'dairy cattle in milk' used in earlier inventories. This definition includes 'cows in calf but not in milk'. The waste factors used for beef and other cattle are now calculated from the IPCC Tier 2 procedure but do not vary from year to year. Emission factors and base data for beef and other cattle are given in Table A43.

Table A44 Cattle Manure Management Systems in the UK

Manure Handling System	Methane Conversion Factor %	Fraction of manure handled using manure system %	Fraction of manure handled using manure system %
		Dairy	Beef and Other
Pasture Range	1	43	50
Liquid System	10	38	14
Solid Storage	1	10	27
Daily Spread	0.1	9	9

3.14.1.3 Emissions of Nitrous Oxide from Animal Waste Management Systems

Animals are assumed not to give rise to nitrous oxide emissions directly, but emissions from their wastes during storage are calculated for a number of animal waste management systems (AWMS) defined by IPCC. Emissions from the following AWMS are reported under the IPCC category, manure management.

- Flushing Anaerobic Lagoons. These are assumed not to be in use in the UK.
- Liquid systems
- Solid storage and dry lot
- Other systems (farmyard manure, poultry litter, stables)

According to IPCC (1997) guidelines, the following AWMS are reported in the Agricultural Soils category

- Daily spread
- Pasture range and paddock

Emissions from the combustion of poultry litter for electricity generation are reported under power stations.

The IPCC (1997) method for calculating emissions of N_2O from animal waste management systems can be expressed as:

$$N_2O_{(AWMS)} = 44/28 \cdot \sum N_T \cdot Nex_{(T)} \cdot AWMS_{(T)} \cdot EF_{(AWMS)}$$

where

$N_2O_{(AWMS)}$	=	N_2O emissions from animal waste management systems (kg N_2O/yr)
N_T	=	Number of animals of type T
$Nex_{(T)}$	=	N excretion of animals of type T (kg N/animal/yr)
$AWMS_{(T)}$	=	Fraction of Nex that is managed in one of the different waste management systems of type T
$EF_{(AWMS)}$	=	N_2O emission factor for an AWMS (kg N_2O-N/kg of Nex in AWMS)

The summation takes place over all animal types and the AWMS of interest. Animal population data were taken from MAFF Statistics (MAFF, 1999b). Table A45 shows emission factors for nitrogen excretion per head for domestic livestock in the UK (Nex). These have been revised since the 1996 Inventory, based on a new balance by Smith (1998). The UK methodology assumes that 20% of the total N emitted by livestock volatilises as NO_x and NH_3 and therefore does not contribute to N_2O emissions from AWMS. Hence the Nex factors used in the AWMS estimates and those reported in Tables A45 and A46 exclude the fraction of N volatilising. Hence they are 20% less than if they were reported on the same basis as the 'total' Nex factors reported in the IPCC Guidelines. The estimates of total N excreted reported in the Common Reporting Format are not corrected in this way and report total N excreted from livestock. Nex factors for dairy cattle take account of the assumed growth in the average cow weight by 1% per annum and are shown in Table A46. The conversion of excreted N into N_2O emissions is determined by the type of waste management system used. The distribution of waste management systems for each animal type ($AWMS_{(T)}$) is given in Table A47. Table A48 gives the N_2O emission factor for each animal waste management system ($EF_{(AWMS)}$). These are expressed as the emission of N_2O-N per mass of excreted N processed by the waste management system.

Emissions from grazing animals (pasture range and paddock) and daily spread are calculated in the same way as the other AWMS. However, emissions from land spreading of waste that has previously been stored in liquid systems, other systems, solid storage and dry lot are treated differently. These are discussed in Section 3.14.2.6 on Organic Fertilizer.

Table A45 Nitrogen Excretion Factors for Animals in the UK[1]

Animal Type	Emission Factor kg N/animal/yr[2]
Dairy cows	92.9[3]
Other cattle > 2yr	60
Other cattle 1-2 yr.	47
Other cattle >1	11.8
Pigs < 20kg	3
Other Pigs 20-50 kg	7.1
Fattening & Other Pigs > 50 kg	10.7
Breeding pigs > 50 kg	14.3
Breeding Sheep	9.2
Other Sheep <1	9.2[5]
Lambs	3.36[5]
Goats	6.4
Broilers	0.495
Broiler Breeders	0.899
Layers	0.589
Ducks,	0.984
Turkeys	1.052
Growing Pullets	0.106
Other Poultry	0.49
Horses	32
Deer: Stags[4]	17.5
Deer: Hinds[4]	11.7
Deer: Calves[4]	8.64

1   Smith (1998)
2   Nex factors exclude 20% N volatilising as NO_x and NH_3
3   Estimate for year 1998
4   Sneath *et al*, (1997)
5   Factor quoted assumes animal lives for a year. Emission calculation assumes animal lives for 6 months.

Table A46 Nitrogen Excretion Factors for Dairy Cattle[1]

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Emission Factor kg N/animal/yr.	84.8	85.8	86.8	87.7	88.7	89.8	90.8	91.8	92.9

1   Nex factors exclude 20% N volatilising as NO_x and NH_3

Table A47 Distribution of Animal Waste Management Systems used for Different Animal types[c]

Animal Type	Liquid System	Daily Spread	Solid Storage and dry lot[a]	Pasture range and paddock	Other[b]	Fuel
Dairy cows	38	9	10	43	0	
Other cattle	14	9	27	50	0	
Fattening & Other Pigs > 50 kg, (1990–97)[e]	59	14	27	0	0	
Breeding sows (1990–97)[e]	41	10	19	30	0	
Weaner Pigs (1990-97)[e]	53	13	24	10	0	
Finishing Pigs (1990-97)[e]	59	14	27	0	0	
Sheep	0	0	2	98	0	
Goats	0	0	0	96	4	
Broilers, Pullets(1970–91)[f]				1	99	0
Broilers, Pullets (1992-96)[f]				1	64	35
Layers (1970-91)[f]				10	90	0
Layers (1992-96)[f]				10	89	1
Ducks, Geese & Guinea Fowl[f]				50	50	0
Turkeys[f]				8	92	0
Horses				96	4	0
Deer: Stags[d]				100	0	
Deer: Hinds & Calves[d]				75	25	

a	Farmyard Manure
b	Poultry Litter, Stables
c	ADAS(1995a)
d	Sneath *et al* (1997)
e	Agricultural Economics Unit Exeter University (1996)
f	Tucker (1997)

Table A48 Nitrous Oxide Emission Factors for Animal Waste Handling Systems[a]

Waste Handling System	Emission Factor kg N_2O–N per kg N excreted
Liquid System	0.001
Daily Spread[b]	0
Solid Storage and Dry Lot	0.02
Pasture, Range and Paddock[b]	0.02
Fuel	–
Other	0.005

a	IPCC(1997)
b	Reported under Agricultural Soils

3.14.2 Agricultural Soils

Direct emissions of nitrous oxide from agricultural soils are estimated using the IPCC recommended methodology (IPCC, 1997) but using some recently derived UK specific emission factors. This involves estimating contributions from:

(i)   The use of inorganic fertilizer
(ii)   Biological fixation of nitrogen by crops
(iii) Ploughing in crop residues
(iv)   Cultivation of histosols (organic soils)
(v)   Spreading animal wastes on land
(vi)   Manures dropped by animals grazing in the field

In addition to these, the following indirect emission sources are estimated:

(vii) Emission of N_2O from atmospheric deposition of agricultural NO_x and NH_3.
(viii)Emission of N_2O from leaching of agricultural nitrate and runoff.

Descriptions of the methods used follow.

3.14.2.1 Inorganic Fertiliser

Emissions from the application of inorganic fertiliser are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(SN)} = 44/28 \cdot N_{FERT} \cdot (1-Frac_{GASF}) \cdot EF_1$$

where

$N_2O_{(SN)}$ = Emission of N_2O from synthetic fertiliser application (kg N_2O/yr)

N_{FERT} = Total use of synthetic fertiliser (kg N/yr)

$Frac_{GASF}$ = Fraction of synthetic fertiliser emitted as NO_x + NH_3
           = 0.1 kg NH_3–N+NO_x –N / kg synthetic N applied

EF_1 = Emission Factor for direct soil emissions
           = 0.0125 kg N_2O-N/kg N input

Annual consumption of synthetic fertiliser is estimated based on crop areas (MAFF, 1999b) and fertiliser application rates (BSFP, 1999).

3.14.2.2 Biological Fixation of Nitrogen by Crops

Emissions of nitrous oxide from the biological fixation of nitrogen by crops are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(BF)} = 44/28 \cdot 2 \cdot Crop_{BF} \cdot Frac_{NCRBF} \cdot EF_1$$

where

$N_2O_{(BF)}$ = Emission of N_2O from biological fixation (kg N_2O/yr)

$Crop_{BF}$ = Production of legumes (kg dry mass/year)

$Frac_{NCRBF}$ = Fraction of nitrogen in N fixing crop
           = 0.03 kg N/ kg dry mass

EF_1 = Emission Factor for direct soil emissions
           = 0.0125 kg N_2O-N/kg N input

The factor of 2 converts the edible portion of the crop reported in agricultural statistics to the total biomass. The fraction of dry mass for the crops considered is given in Table A49

Table A49 Dry Mass Content and Residue Fraction of UK Crops

Crop Type	Fraction dry Mass[b]	Residue/ Crop
Broad Beans, Green Peas	0.08	1.1
Field Bean[d], Peas(harvest dry)	0.86	1.1
Rye, Mixed corn, triticale	0.855[a]	1.6
Wheat, Oats	0.855[a]	1.3
Barley	0.855[a]	1.2
Oil Seed Rape, Linseed	0.91[a]	1.2
Maize	0.50	1
Hops[c]	0.20	1.2
Potatoes	0.20	0.4
Roots, Onions	0.07	1.2
Brassicas	0.06	1.2
Sugar Beet	0.1	0.2
Other	0.05	1.2
Phaseolus beans	0.08	1.2

a   MAFF(1999b)
b   Burton (1982), Nix (1997) or MAFF estimates
c   Hops dry mass from Brewers Licensed Retail Association(1998)
d   Field beans dry mass from PGRE (1998)

The data for residue/crop were taken from IPCC (1997) defaults in the Agricultural Soils section, or derived from Table 4.17 of the Field Burning of Agricultural Residues section. Crop production data were taken from MAFF (1999b, 1999d). The total nitrous oxide emission reported also includes a contribution from improved grass calculated using a fixation rate of 4 kg N/ha/yr (Lord, 1997).

3.14.2.3 Crop Residues
Emissions of nitrous oxide from the ploughing in of crop residues are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(CR)} = 44/28 \cdot 2 \cdot (Crop_O \cdot Frac_{NCRO} + Crop_{BF} \cdot Frac_{NCRBF})(1-Frac_R) \cdot (1-Frac_B) \, EF_1$$

where

$N_2O_{(CR)}$ = Emission of N_2O from crop residues (kg N_2O/yr)
$Crop_O$ = Production of non-N fixing crops (kg dm/yr.)
$Frac_{NCRO}$ = Fraction of nitrogen in non-N fixing crops
= 0.015 kg N/ kg dm
$Frac_R$ = Fraction of crop that is remove from field as crop
$Frac_B$ = Fraction of crop residue that is burnt rather than left on field
EF_1 = Emission Factor for direct soil emissions
= 0.0125 kg N_2O-N/kg N input
$Crop_{BF}$ = Production of legumes (kg dry mass/year)
$Frac_{NCRBF}$ = Fraction of nitrogen in N fixing crop

= 0.03 kg N/ kg dry mass

Production data of crops were taken from MAFF (1999b, 1999d). The dry mass fraction of crops and fraction of crop removed from the field are given in Table A49. Field burning has largely ceased in the UK since 1993. For years prior to 1993, field burning data were taken from the annual MAFF Straw Disposal Survey. (MAFF, 1995)

3.14.2.4 Histosols

Emissions from histosols were estimated using the IPCC (1997) default factor of 5 kg N_2O–N/ha/yr. The area of cultivated histosols is assumed to be equal to that of eutric organic soils in the UK and is based on a FAO soil map figure supplied by SSLRC.

3.14.2.5 Grazing Animals

Emissions from wastes dropped by grazing animals are classified under agricultural soils by IPCC. The method of estimation is the same as that for AWMS in Section 3.14.1.3 but applying factors for pasture range and paddock.

3.14.2.6 Organic Fertilisers

Emissions from animal wastes used as organic fertilisers are classified under agricultural soils by IPCC. The procedure involves estimating the amount of nitrogen applied to the land and applying IPCC emission factors. For daily spreading of waste, the emission is given by:

$$N_2O_{(DS)} \quad = 44/28 \cdot \sum N_T \cdot Nex_{(T)} \cdot AWMS_{(T)} \cdot EF_1$$

where

$N_2O_{(DS)}$	= N_2O emissions from daily spreading of wastes (kg N_2O/yr)
N_T	= Number of animals of type T
$Nex_{(T)}$	= N excretion of animals of type T (kg N/animal/yr)
$AWMS_{(T)}$	= Fraction of Nex that is daily spread
EF_1	= Emission Factor for direct soil emissions
	= 0.0125 kg N_2O–N/kg N input

For the application of previously stored wastes to land, a correction is applied to account for N_2O losses during storage.

$$N_2O_{(FAW)} \quad = 44/28 \cdot \sum (N_T \cdot Nex_{(T)} \cdot AWMS_{(T)} - N_{(AWMS)}) \cdot EF_1$$

where the summation is for all animal types and for liquid system, solid storage and other systems where wastes are stored.

$N_2O_{(FAW)}$	= N_2O emission from organic fertiliser application
$N_{(AWMS)}$	= N_2O emissions from animal waste management systems as nitrogen (kg N_2O–N/yr)
N_T	= Number of animals of type T
$Nex_{(T)}$	= N excretion of animals of type T (kg N/animal/yr)
$AWMS_{(T)}$	= Fraction of Nex that is managed in one of the different waste management systems of type T

3.13.2.7 Atmospheric Deposition of NO_x and NH_3

Indirect emissions of N_2O from the atmospheric deposition of ammonia and NO_x are estimated according to the IPCC (1997) methodology but with corrections to avoid double counting N. The sources of ammonia and NO_x considered, are synthetic fertiliser application and animal wastes applied as fertiliser.

The contribution from synthetic fertilisers is given by:

$$N_2O_{(DSN)} = 44/28 \cdot (N_{(FERT)} - N_{(SN)}) \cdot Frac_{(GASF)} \cdot EF_4$$

where

$N_2O_{(DSN)}$ = Atmospheric deposition emission of N_2O arising from synthetic fertiliser application (kg N_2O)

$N_{(FERT)}$ = Total mass of nitrogen applied as synthetic fertiliser (kg N)

$N_{(SN)}$ = Direct emission of $N_2O_{(SN)}$ as nitrogen (kg N_2O-N)

$Frac_{(GASF)}$ = Fraction of total synthetic fertiliser nitrogen that is emitted as NO_x + NH_3
            = 0.1 kg N/ kg N

EF_4 = N deposition emission factor
            = 0.01 kg N_2O-N/kg NH_3-N and NO_x-N emitted

The estimate includes a correction to avoid double counting N_2O emitted from synthetic fertiliser use.

The indirect contribution from waste management systems is given by

$$N_2O_{(DWS)} = 44/28 \cdot (N_{(EX)}/(1-Frac_{(GASM)}) - N_{(F)}) \cdot Frac_{(GASM)} \cdot EF_4$$

where

$N_2O_{(DWS)}$ = Atmospheric deposition emission of N_2O arising from animal wastes (kg N_2O)

$N_{(EX)}$ = Total N excreted by animals

$Frac_{(GASM)}$ = Fraction of livestock nitrogen excretion that volatilises as NH_3 and NO_x
            = 0.2 kg N/kg N

$N_{(F)}$ = Total N content of wastes used as fuel (kg N)

The equation corrects for the N content of wastes used as fuel but no longer for the N lost in the direct emission of N_2O from animal wastes as previously. The nitrogen excretion data in Table A45 already exclude volatilisation losses and hence a correction is included for this.

3.14.2.8 Leaching and Runoff

Indirect emissions of N_2O from leaching and runoff are estimated according the IPCC methodology but with corrections to avoid double counting N. The sources of nitrogen considered, are synthetic fertiliser application and animal wastes applied as fertiliser.

The contribution from synthetic fertilisers is given by:

$N_2O_{(LSN)}$ $= 44/28 \cdot (N_{(FERT)} \cdot (1-Frac_{(GASF)}) - N_{(SN)}) \cdot Frac_{(LEACH)} \cdot EF_5$

where

$N_2O_{(LSN)}$	= Leaching and runoff emission of N_2O arising from synthetic fertiliser application (kg N_2O)
$N_{(FERT)}$	= Total mass of nitrogen applied as synthetic fertiliser (kg N)
$N_{(SN)}$	= Direct emission of $N_2O_{(SN)}$ as nitrogen (kg N_2O-N)
$Frac_{(GASF)}$	= Fraction of total synthetic fertiliser nitrogen that is emitted as NO_x + NH_3
	= 0.1 kg N/ kg N
$Frac_{(LEACH)}$	= Fraction of nitrogen input to soils that is lost through leaching and runoff
	= 0.3 kg N/ kg fertiliser or manure N
EF_5	= Nitrogen leaching/runoff factor
	= 0.025 kg N_2O-N /kg N leaching/runoff

The estimate includes a correction to avoid double counting N_2O emitted from synthetic fertiliser use.

The indirect contribution from waste management systems is given by

$N_2O_{(LWS)}$ $= 44/28 \cdot (N_{(EX)} - N_{(F)} - N_{(WS)}) \cdot Frac_{(LEACH)} \cdot EF_5$

where

$N_2O_{(LWS)}$	= Leaching and runoff emission of N_2O from animal wastes (kg N_2O)
$N_{(EX)}$	= Total N excreted by animals (kg N)
$N_{(F)}$	= Total N content of wastes used as fuel (kg N)
$N_{(AWMS)}$	= Total N content of N_2O emissions from waste management systems including daily spread and pasture range and paddock (kg N_2O-N)

The equation corrects both for the N lost in the direct emission of N_2O from animal wastes and the N content of wastes used as fuel.

3.13.3 Field Burning.

The NAEI estimates emissions from field burning under the category agricultural incineration. The estimates are derived from emission factors calculated according to IPCC (1997) and from USEPA (1997) shown in Table A50

Table A50 Emission Factors for Field Burning (kg/t)

	CH_4	CO	NO_x	N_2O	NMVOC
Barley	3.05[a]	63.9[a]	2.18[a]	0.060[a]	7.5[b]
Other	3.24[a]	67.9[a]	2.32[a]	0.064[a]	9[b]

a   IPCC (1997)
b   USEPA (1997)

The estimates of the masses of residue burnt of barley, oats, wheat and linseed are based on crop production data (MAFF, 1999d) and data on the fraction of crop residues burnt (MAFF, 1997; ADAS (1995b)). Field burning ceased in 1993 in England and Wales. Burning in Scotland and Northern Ireland is considered negligible, as is grouse moor burning, so no estimates are reported from 1993 onwards. The carbon dioxide emissions are not estimated because these are part of the carbon cycle.

3.15 LAND USE CHANGE AND FORESTRY

3.15.1 Introduction[†]
The estimates for Land Use Change and Forestry are from work done by the Centre for Ecology and Hydrology (Cannell *et al.* 1999, Milne and Brown 1999). The data are reported under IPCC categories 5A to 5E.

3.15.2 Changes in Forests and Other Woody Biomass Stocks (5A)
The estimates are based on data for the areas of forest plantation published by the UK Forestry Commission and the Northern Ireland Department of Agriculture. The carbon uptake is calculated by a carbon accounting model (Dewar and Cannell 1992, Cannell and Dewar 1995, Milne *et al.* 1998) as the net change in pools of carbon in standing trees, litter, soil in broadleaf forests and products. There have been no major changes to this method of estimating uptake of carbon by afforestation in the UK since earlier UK GHG Inventories. Conifer forest is represented as Sitka spruce (Yield Class 12 in GB and Yield Class 14 in NI) and broadleaf forest is represented as beech (Yield Class 6). All commercial forest is assumed to be restocked. Milne *et al.* (1998) have shown that allowing for yield class to vary across the country has only a small effect (about 10%) on estimated uptake rates of carbon. Deforestation is considered to be negligible.

It should be noted that for consistency with previous reports those parts of the net uptake by litter, soils and products are included in the data reported in this category. The values of these

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[†] The land use change and forestry estimates were provided by the Centre for Ecology and Hydrology (Contract EPG/1/1/39). Technical enquiries on land use change and forestry should be addressed to Dr R Milne, Centre for Ecology and Hydrology, Bush Estate, Penicuik, EH26 OQB, UK (tel +44 (0) 131 445 8575. fax +44 (0) 131 445 3943, E-mail, rmilne@ceh.ac.uk

removals are also provided in footnotes to the Tables to allow comparison with data from countries which report only changes in woody biomass and include soils etc. elsewhere and with data provided in the Common Reporting Format

3.15.3 CO$_2$ Emissions and Removals from Soils (5D)
Three processes are reported in this category: changes in soil stocks due to land use change, change in soil stocks due specifically to the change in land use from arable in Set Aside schemes and emissions due to the application of lime and dolomite.

3.15.3.1 Land Use Change
The basic method for assessing changes in soil carbon due to land use change is to use a matrix of change from surveys of land linked to a dynamic model of gain or loss of carbon. In the latest version of the method matrices from the Monitoring Landscape Change (MLC) data from 1947 & 1980 and the DETR/ITE Countryside Surveys (CS) of 1984 & 1990 are used. Land use in the UK can be placed into 4 broad groups – (Semi) Natural, Farming, Woodland and Urban – and hence the more detailed categories for the two surveys were combined as shown in Table A51a for MLC and A51b for CS. In both cases only unimproved grassland is included in the Natural category. For the CS the different types of grass are shown in Table A52.

A database of soil carbon density for the UK has been constructed (Milne and Brown 1997, Cruickshank *et al.* 1998) from information provided by the Soil Survey and Land Research Centre, the Macaulay Land Use Research Institute and Queen's University Belfast on soil type, land cover and carbon content of soil cores.

The mean carbon density for farm cropland land in GB from the database is 152 t/ha and for grassland is 179 t/ha. Although the latter value includes both improved and unimproved grasses there is therefore no strong evidence of a major difference in the soil carbon density of tilled cropland or actively managed grass hence the inclusion of both uses within the Farm category.

Table A51a: Grouping of MLC land cover types for soil carbon change modelling.

FARM	NATURAL	WOODLAND	URBAN
Crops	Upland heath	Broadleaved wood	Built up
Market garden	Upland smooth grass	Conifer wood	Urban open
Improved grassland	Upland coarse grass	Mixed wood	Transport
Rough pasture	Blanket bog		Mineral workings
	Bracken		Derelict
	Lowland rough grass		
	Lowland heather		
	Neglected grassland		
	Marsh		

Table A51b: Grouping of CS land cover types for soil carbon change modelling. For Managed grass (I) signifies "Improved", usually by ploughing and seeding, (U) signifies "Unimproved" by such means.

FARM	NATURAL	WOODLAND	URBAN
Tilled land	Rough grass/marsh	Broadleaved/mixed	Communications
Managed grass(I)	Managed grass (U)	Coniferous	Built up
	Dense bracken		Inland bare (Hard areas)
	Moorland grass		
	Dense heath		
	Open heath		

Table A52: Different types of CS land cover included in the "Improved" and "Unimproved" groups for soil carbon modelling.

Managed grass (I)	Managed grass (U)
Recreational	Non–agricultural improved
Recently sown	Calcareous
Pure rye	Upland
Well managed	
Weedy swards	

Table A53. Area and change data sources for different periods in estimation of changes in soil carbon. (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

Year or Period	Area data	Change matrix or data
1930	Land use Survey (1)	
1930 – 1947	*Interpolated*	MLC 1947->MLC1980
1947	MLC (2)	
1947–1980	*Interpolated*	MLC 1947->MLC1980
1980	MLC (2)	
1980–1984	*Interpolated*	*Interpolated*
1984	CS1984 (3)	
1984–1990	*Interpolated*	CS1984->CS1990
1990	CS1990 (3)	
1990–2010	*Extrapolated from 84->90*	CS1984->CS1990

Area data exist for the period 1930 to 1990 and those from 1984 to 1990 are used to extrapolate forward for the years 1991 to 1998. Land use change matrices for the periods 1947 to 1980 and 1984 to 1990 are used. See Table A53 for the sources of information for land use and matrices of change.

The core equation describing changes in soil carbon with time for any land use transition is

$$C_t = C_f - (C_f - C_0)e^{-kt}$$

C_t is carbon density at time t
C_0 is carbon density initially
C_f carbon density after change to new land use
k is time constant of change

If the inventory year is 1990 and A_T is area in a particular land use transition in year T considered from 1930 onwards then total carbon lost or gained from 1930 to 1990 (X_{1990}) and from 1930 to 1989 (X_{1989}) is given by

$$X_{1990} = \sum_{T=1930}^{t=1990} A_T (C_0 - C_f)(1 - e^{-k(1990-T)})$$

$$X_{1989} = \sum_{T=1930}^{T=1989} A_T (C_0 - C_f)(1 - e^{-k(1989-T)})$$

Hence flux of carbon in 1990 is given by difference:

$$F_{1990} = X_{1990} - X_{1989}$$

The land use transitions considered are each of those between the (Semi) Natural, Farm, Woodland and Urban categories. Scotland, England and Wales are treated separately. Northern Ireland does not yet have a matrix of land use change and changes in soil carbon are calculated by a method based on that recommended by the IPCC (1997b, c). The area data for Great Britain are shown in Table A54. The data from the CS has had a small adjustment applied to account for one of the detailed land types (Non-cropped arable) actually bridging the main Natural and Farm categories.

Table A54a Area of land in England for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

		Area(ha)			
Source	Year	Farm	Natural	Urban	Woodland
Lus (1)	*1930*	9,542,340	1,543,000	1,034,858	843,800
mlc (2)	*1947*	9,242,777	1,639,511	823,665	865,370
mlc (2)	*1980*	9,013,401	1,307,178	1,301,965	948,779
Cis (3)	*1984*	8,670,815	1,908,436	1,249,383	1,303,455
Cis (3)	*1990*	8,336,428	2,120,609	1,323,084	1,353,399

Table A54b Area of land in Wales for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

		Area(ha)			
Source	Year	**Farm**	**Natural**	**Urban**	**Woodland**
lus (1)	*1930*	1,094,187	771,520	77,298	120,439
mlc (2)	*1947*	1,061,571	701,347	71,422	160,077
mlc (2)	*1980*	1,148,150	521,131	121,459	203,677
cis (3)	*1984*	1,155,174	585,248	176,112	221,521
cis (3)	*1990*	1,132,768	593,918	188,628	222,953

Table A54c Area of land in Scotland for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

		Area(ha)			
Source	**Year**	**Farm**	**Natural**	**Urban**	**Woodland**
lus (1)	*1930*	1,861,215	5,265,673	146,906	443,187
mlc (2)	*1947*	2,037,860	5,209,630	260,313	447,753
mlc (2)	*1980*	2,100,125	4,667,711	297,076	890,644
cis (3)	*1984*	2,109,333	4,940,892	287,471	1,019,931
cis (3)	*1990*	2,059,553	4,935,184	294,291	1,068,543

In the model the change in equilibrium carbon density from the initial to the final land use during a transition is required. Here, these are calculated for each land use category as averages for Scotland, England and Wales. In order to account for variation in carbon density and Land Use Change in different soil types these averages are weighted by the area of soil groups used by IPCC (1997c). They define five groups, which are represented in Great Britain, on the basis of their carbon content and activity namely; aquic, high activity clay, low activity clay, sandy and organic. In Great Britain few clay soils truly fall into the 'high activity' class so the total clay content is used to divide these soils into 'high' and 'low' groups. For Great Britain all soil types not falling into these five types an 'undefined' groups is used. Mean soil carbon density changes are calculated as.

$$\overline{C}_{ijc} = \frac{\sum_{s=1}^{6}(C_{sijc}L_{sijc})}{\sum_{s=1}^{6}L_{sijc}}$$

which is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes and
i = initial land use (Natural, Farm, Woods, Urban)
j = new land use   (" ")
c = country   (Scotland, England & Wales)

s = soil group (High clay, low clay, aquic, organic, sandy, undefined)
C_{sijc} is change in equilibrium soil carbon for a specific land use transition
within a soil group region in a specific country
L_{sijc} is area change (1984 to 1990) for a specific land use transition within a soil group region in a specific country.

The rate of loss or gain of carbon is dependent on the type of land use transition (Table A55). For transitions where carbon is lost e.g. transition from Natural to Farm land, a 'fast' rate is applied which is equivalent to 99% of the change in soil carbon being complete in 20 years whilst a transition which gains carbon occurs much more slowly. This 'slow' rate had prior to the 1997 GHG Inventory been set such that 99% of the change occurred in 100 years throughout GB as had been observed at Rothamstead (Howard *et al.* 1994). However, it was observed that due to the high carbon densities in Scottish soils that the uptake rates of carbon in that country were unreasonably large when land moved to the Natural class from the Farm class. The rate of uptake was therefore reduced until the uptake of soil carbon in such transitions was less than the order of net primary productivity for cold temperate grasslands (about 300 g m^{-2}a^{-1}). Thus a rate of soil carbon accumulation in Scotland which took the equivalent of 800 years to reach 99% of the new values is used.

Table A55. Rates of change of soil carbon for land use change transitions. ("Fast" refers to 99% of change occurring in 20 years, "Slow" refers to 99% of change occurring in100 years in England & Wales but 800 years in Scotland)

		1984			
		Farm	**Natural**	**Urban**	**Woods**
1990	**Farm**		*fast*	*slow*	*fast*
	Natural	*slow*		*slow*	*fast*
	Urban	*fast*	*fast*		*fast*
	Woods	*slow*	*slow*	*slow*	

3.15.3.2 Method for Set Aside
The estimation of changes in soil carbon calculated by the matrix method for all transitions does not fully include the effects of the policy of Set Aside from production of arable areas. This is the case because although the schemes were introduced in 1988 there was a slow rate of acceptance by farmers and it was not until after 1990 that significant areas are recorded in the Annual Farm Census. In this post-1990 period the matrix method uses an extrapolation of the CS field data from 1984 to 1990 therefore a separate estimate of the effect of Set Aside on soil carbon for these later years has been made. Data reported in inventories prior to 1997 were based on the observation from the Annual Farm Census that Set Aside was continuing to increase in total area. However from more recent Census data it would seem that the total area has now passed its maximum and is beginning to fall. This reflects the fact that the Schemes will be phased out, to be replaced with others with different objectives. The data reported here therefore take into account not only the effect of soil carbon increasing in areas where land is not used for arable purposes but the subsequent loss of the extra accumulated carbon from the soil when land is returned to arable use.
Set Aside areas are taken from the Annual Farm Census for Scotland and England & Wales separately. Scottish soils coming out of arable use are assumed to be able to take up 500 t/ha but that this happens at a rate which would only allow 99% of that change to occur in 800 years as assumed in the general land use calculation. For English & Welsh soils it is assumed that the

change in equilibrium soil carbon density would be 60 t/ha and that 99% of this change would occur in 100 years. The new areas of land in Set Aside are calculated from the increases in area up to the maximum total recorded area (in 1995 throughout GB). The emission of carbon from these areas are calculated for years up until 1999 when it is assumed that all land will have returned to arable. To compensate for the reducing area, two assumptions were made: a) the area lost in each year from 1995 onwards was assumed to have been in Set Aside for 3 years and b) the carbon gained in these 3 years would be lost at a rate which would cause 99% of the change to occur in 20 years. The 3 year assumption is made as there is no clear indication of how long any area does remain in Set Aside. This value is not unreasonable but may be low given that some Set Aside could have existed from 1988. Previously it was assumed that all Set Aside was simply abandoned but between 30 and 50% is actually managed by cutting etc. Such areas will not be very different from other rotational pasture situations which we have already shown to have similar soil carbon to arable areas. Hence such areas have been excluded from estimates of the effect of Set Aside reported here.

Thus for the estimates reported here the assumptions are: Set Aside area rises to a maximum in 1995 then fall away to zero by 1999, uptake occurs slowly in Scotland and 50% of areas in Census are in rotational form of management are excluded. Northern Ireland has negligible change in soil carbon due to Set Aside

3.15.3.2 Emissions of CO_2 from soil due to liming

Emissions of carbon dioxide from the application of limestone, chalk and dolomite to agricultural soils were estimated. Data on the use of limestone, chalk and dolomite for agricultural purposes are reported in BGS (2000). It is assumed that all the carbon contained in the lime is released in the year of use. For limestone and chalk, a factor of 120 t C/kt is used, and for dolomite application, 130 t C/kt. These factors are based on the stoichiometry of the reaction and assume pure limestone and dolomite.

3.15.4 Other sources and sinks (5E)

These are:
Sources
- Drainage of deep peat
- Drainage of lowland wetlands
- Peat extraction

and sink
- Changes in crop biomass

The activity data and carbon fluxes are based on data from (Bradley 1997, Cannell *et al*. 1993, Cruickshank *et al*. 1997, Hargreaves and Fowler 1997) for sources and from (Adger and Subak 1996) for the sink.

Changes in Crop Biomass
This value was originally derived by Adger & Subak (1996) using Agricultural Census and other data up to 1992. For the 1998 Inventory more recent data from the Agricultural Census

were considered but did not support any change to the existing estimate. This rate is therefore reported for all years from 1990 to 1998.

Peat Extraction

Trends in peat extraction in Scotland and England over period 1990 to 1998 are now included. In Northern Ireland no new data on use of peat for horticultural use were available and a recent survey of extraction for fuel use suggested that there is no significant trend for this purpose. The contribution of emissions due to peat extraction is therefore incorporated as constant from 1990 to 1998. Peat extraction is negligible in Wales.

Lowland (fen) peat drainage

The trend in emissions due to changing areas of drainage is now included based on information previously unused in the work of Bradley (1997).

Upland (forestry) peat drainage

The area of forestry on peat is unlikely to have changed due to present policy. Emissions from planted areas tend to exist for considerable periods due to the large stock of carbon that is available for decomposition and hence the emissions included under this heading are reported as constant from 1990 to 1998.

The sources are summarised in Tables A56 and A57 and also detailed in footnotes to IPCC Table 5E.

Table A56 Summary of Emission Factor Data for Deep Peat Drainage and Lowland Wetland Drainage

	Emission Factor g C/m^2/y
Deep Peat Drainage	200
Lowland Wetland	297

Table A57 Summary of Data for Peat Extraction (GB Great Britain, NI Northern Ireland)

	Emission Factor	
	kg C m^{-3}	Gg C/Gg
GB Horticultural Peat	55.7	–
GB Fuel Peat	55.7	–
NI Horticultural Peat	44.1	–
NI Fuel Peat	–	0.3

3.16 WASTE

3.16.1 Landfill

The NAEI category Landfill maps directly on to 6A1 Landfills for methane emissions. Emissions are reported from landfills only, as open dumps are considered insignificant in the UK.

The estimation of methane emissions from landfill is uncertain because the amount of waste disposed of to landfill is not reliably known. The NAEI estimate is based on a study by Brown *et al* (1997). The main features of this model are:

- The methane generation of current and historical waste was assumed to follows a first order model.
- Landfill sites were classified into four types each with different methane generation and collection characteristics.
    1. Those with no gas control
    2. Those with limited gas control
    3. Those with comprehensive gas control
    4. Old sites which closed before 1980
- Waste arisings, and waste composition data were compiled using the latest UK national statistics, together with an analysis of past trends in waste generation and disposal.
- Data on methane generation, oxidation and collection has also been collected, from literature studies and expert opinion, together with an analysis of past trends in landfill design and management specific to the UK
- Waste can be divided into three fractions which decay at different rates – these are classified as rapidly degradable, moderately degradable and slowly degradable organic fractions.
- A full review of baseline data for input to the model was undertaken. Data on the division of waste between sites with different degrees of methane control was based on the Environment Agency's landfill GIS database. Waste arisings and composition were based on national statistics supplemented by new analysis. Parameters governing methane generation, such as the carbon content and decay rates of the waste, were based on literature studies supplemented by expert opinion.

The emissions of pollutants from the flare stacks were not estimated but those from electricity generation and heat generation were. Emissions from electricity generation are considered under Power Stations in Section 3.3.1. Emissions from heat generation are included in the base combustion module under Miscellaneous.

An estimate of NMVOC was made using an emission factor of 0.01 t NMVOC/ t methane produced which is equivalent to 5.65g NMVOC/ m^3 landfill gas (Passant, 1993).

Neither the GHGI nor the NAEI reports carbon dioxide emissions from the anaerobic decay of landfilled waste since this is considered to be part of the carbon cycle and is not a net source.

The estimates include the contribution of sewage disposed of to landfill.

3.16.2 Waste Water Treatment

The NAEI category Sewage is mapped on to the IPCC category 6B2 Domestic and Commercial Wastewater. There is no estimate made of emissions from private wastewater treatment plants operated by companies prior to discharge to the public sewage system or rivers. The NAEI estimate is based on the work of Hobson *et al* (1996) who estimated emissions of methane for the years 1990-95. Subsequent years are extrapolated on the basis of population. Sewage disposed of to landfill is included in landfill emissions.

Nitrous oxide emissions from the treatment of human sewage are based on the IPCC (1997c) default methodology. The average protein consumption per person is based on the National Food Survey.

3.16.3 Waste Incineration

The NAEI estimates emissions from the categories Incineration: MSW and Incineration: Sewage. These are mapped onto the single NAEI category 6C Waste Incineration. The emission factors used are shown in Table A58.

Table A58 Emission Factors for Waste Incineration (kg/t waste)

	C^1	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
MSW(old)	75[a]	0.0008[d]	0.148[b]	1.8[c]	0.709[c]	0.0231[d]	1.36[c]
Sewage	0	0.39[b]	0.227[b]	2.5[b]	15.5[b]	0.84[b]	2.3[e]

    1   Emission factor as kg carbon/ t waste
    a   Royal Commission on Environmental Pollution (1993)
    b   EMEP/CORINAIR(1996).
    c   Clayton *et al.* (1991)
    d   Estimated from THC data in CRI (Environment Agency, 1997a) assuming 3.3% methane split given in EMEP/CORINAIR(1996)
    e   EMEP/CORINAIR (1996). A factor of 14 kt/Mt is used prior to 1996.

The arisings of waste and their method of disposal are not known with any reliability. The estimates of municipal solid waste disposed of to incinerators are based on incinerator capacity (Patel *et al.*, 1999). Under IPCC guidelines, incineration refers only to plant that do not generate electricity. From the end of 1996, waste incinerators have had to meet new standards. As a result, many incinerators have closed down, have been renovated or new ones have been built. From 1997 onwards all MSW incinerators generated electricity and are classified as power stations so no emissions are reported under Incineration: MSW. Emission factors for modern incinerators are reported in Table A15. The emission factors given in Table A58 pertain to old incinerators prior to 1993. Emission factors for the years 1993-1996 were derived from the Pollution Inventory (Environment Agency, 1999). Only those emissions of carbon dioxide deriving from recently photosynthesised carbon are estimated. It was assumed that the proportion of recently photosynthesised carbon was 25% of the total carbon content of the waste (Brown, 1995) and this assumption is reflected in the factors in Table A58.

4   Uncertainties in the Estimates

4.1   INTRODUCTION

Quantitative estimates of the uncertainties in the emissions were calculated using direct simulation, a technique similar to Monte Carlo Simulation. This corresponds to the IPCC Tier 2 approach. This work is described in detail by Eggleston *et al* (1998) though the estimates reported here have been revised to reflect changes in the 1998 Inventory. This section gives a brief summary of the methodology, assumptions and results of the simulation.

The general computational procedure was:
1. An uncertainty distribution was allocated to each emission factor and activity rate. The distributions used were either normal, log-normal or uniform. The parameters of the distributions were set by analysing the available data on emission factors and activity data or expert judgement.
2. A calculation was set up to estimate the emission of each gas, carbon dioxide sink, and the global warming potential for the years 1990 and 1998. Using the software tool @RISK™, each uncertainty distribution was sampled 10000 times and the emission calculations performed to formulate a converged output distribution.
3. It was assumed that the distribution of errors in the parameter values was normal. The quoted range of possible error of uncertainty is taken as 2s, where s is the standard deviation. If the expected value of a parameter is E and the standard deviation is s, then the uncertainty is quoted is 2s/E expressed as a percentage. For a normal distribution the probability of the parameter being less than E-2s is 0.025 and the probability of the emission being less than E+2s is 0.975.
4. For methane and nitrous oxide, it was assumed that there was no correlation between emission factors for the same fuels applied to different sources. For CO_2 emission factors for natural gas, gas oil, kerosene, fuel oil, motor gasoline and aviation fuel were correlated with those for the same fuel used in different sources. Activity data were not correlated with each other.
5. To simplify the calculations the uncertainties for total halocarbon and SF_6 emissions were taken from Eggleston *et al* (1998).

4.2   CARBON DIOXIDE EMISSION UNCERTAINTIES

It was necessary to estimate the uncertainties in the activity data and the emission factors for the main sources and then combine them.

The uncertainties in the fuel activity data were estimated from the statistical differences data in DTI (1996). These are effectively the residuals when a mass balance is performed on the production, imports, exports and consumption of fuels. For solid and liquid fuels both positive and negative results are obtained indicating that these are uncertainties rather than losses. For gaseous fuels these figures include losses and tended to be negative. For natural gas, a correction was made to take account of leakage from the gas transmission system but for other gases this was not possible. The other uncertainties for minor fuels (colliery methane, orimulsion, SSF, petroleum coke) and non-fuels (limestone, dolomite and clinker) were estimated based on

judgements based on their relative uncertainty compared with the known fuels. The high uncertainty in the aviation fuel consumption reflects the uncertainty in the split between domestic and international aviation fuel consumption.

The uncertainties in the emission factors were based largely on expert judgement. It was possible to compare the coal emission factors used in the inventory with some recent measurements (Fynes, 1994). Also Transco (1998) data allowed an estimate of the uncertainty in the carbon content of natural gas. The time series data of the gross calorific value of fuels used in the UK (DTI, 1996) would also give *some indication* of the relative variabilities in the carbon contents. Thus the uncertainties in the fuel emission factors were based on judgements on whether they were likely to be similar or less than those of coal or natural gas.

In the case of non-fuel sources, the uncertainty depended on the purity of limestone or the lime content of clinker so the uncertainties estimated were speculative.

The uncertainties in certain sources were estimated directly. Flaring uncertainties were estimated by comparing the 1996 GHGI estimate to that of the SCOPEC (1997) study. Uncertainties in the land use change sources were recalculated (Milne, 1999) for the revised source categories in the IPCC 1996 Guidelines using data from Eggleston *et al* (1998). The overall uncertainty was estimated as around 3.5% in 1990 and 3% in 1998.

Table A59 Estimated Uncertainties in Carbon Dioxide Inventory[1]

Source	Activity Uncertainty %	Emission Factor Uncertainty %	Uncertainty in Emission %
Coal	1.2	6	‡
Coke	5.6	3	‡
Petroleum Coke	5	3	‡
SSF	3	3	‡
Burning Oil	6	2	‡
Fuel Oil	4	2	‡
Gas Oil/Diesel Oil	1.4	2	‡
Motor Spirit	0.8	2	‡
Orimulsion	1	2	‡
Aviation Fuel (Domestic)	50	2	‡
Lubricants	25	5	‡
Natural Gas	2.4	1	‡
Colliery Methane	5	5	‡
LPG	24	3	‡
OPG	1.1	3	‡
Ammonia Production	–	–	5
Cement	1	2	‡
Lime/Limestone/Dolomite	1	5	‡
Soda Ash Use	15	2	‡
Flaring	–	–	14
Other Offshore (well testing)	–	–	28
Iron & Steel Processes	1	20	‡
Aluminium Production	1	5	‡
Waste Incineration	7	20	21
5A Forest Biomass Change[2]	–	–	30
5D Soils[2]	–	–	60
5E Other[2]	–	–	50

1   Expressed as 2s/E
2   Uniform distribution used
‡   Input parameters were uncertainties of activity data and emission factors.

4.3   METHANE EMISSION UNCERTAINTIES

In the methane inventory, combustion sources are a minor source of emissions. The uncertainty in methane combustion emission factors will outweigh the activity errors so an uncertainty of 50% was assumed for combustion sources as a whole. The errors in the major sources are listed in Table A60. These are mainly derived from the source documents for the estimates or from the Watt Committee Report (Williams, 1993). The uncertainty in offshore emissions is based on a comparison of the source data (UKOOA, 1993) and another study on offshore emissions (Woodhill Engineering, 1993)

Table A60 Estimated Uncertainties in the Methane Inventory

Source	Reference	Source Uncertainty %
Fuel Combustion	‡	50
Field Burning	‡	50
Landfill	Brown *et al* 1999	~48[1]
Livestock: enteric	Williams, 1993	20
Livestock: wastes	Williams, 1993	30
Coal Mining	Bennett *et al*, 1995	13
Gas Leakage	Williams, 1993	17–75[2]
Offshore	‡	28
Sewage Sludge	Hobson *et al*, 1996	50

1   Skewed distribution
2   Various uncertainties for different types of main and service
‡   See text

The sources quoted in Table A60 are assumed to have normal distributions of uncertainties with the exception of landfills. Brown et al (1999) estimated the uncertainty distribution for landfill emissions using Monte Carlo analysis and found it to be skewed. For normal distributions there is always a probability of negative values of the emission factors arising. For narrow distributions this probability is negligible, however with wide distributions the probability is higher. In the original work (Eggleston *et al,* 1998) this problem was avoided by using truncated distributions. However, it was found that this refinement made very little difference to the final estimates, so in these estimates normal distributions were used rather than truncated normal.

The emission of methane in 1998 was estimated as 2636 kt. The Monte Carlo analysis suggested that 90% of trials were between 2310 kt and 3030 kt. The uncertainty was around 20%. The emission of methane in 1990 was estimated as 3680 kt. The Monte Carlo analysis suggested that 90% of trials were between 3190 kt and 4260 kt. The uncertainty was around 17%.

4.4   NITROUS OXIDE EMISSION UNCERTAINTIES

The analysis of the uncertainties in the nitrous oxide emissions is particularly difficult because emissions arise from a diverse collection of sources and little data are available to form an assessment of the uncertainties in each source. Emission factor data for the combustion sources are scarce and for some fuels is not available. The parameter uncertainties are shown in Table A61. Emission estimates from agricultural soils have very high uncertainties – typically two orders of magnitude hence the use of a lognormal distribution.

Table A61: Estimated Uncertainties in the Nitrous Oxide Emissions[1]

	Emission Factor Uncertainty %	Activity Rate Uncertainty %
Agricultural Soils	Log-normal[2]	0
Adipic Acid	15	0.5
Nitric Acid	230	15
Coal	195	1.2
Anthracite	387	1.2
Coke	118	5.6
Patent Fuel	118	3
Burning Oil	140	6
Gas Oil	140	1.4
Fuel Oil	140	4
Gasoline	170	0.8
Auto Diesel	170	1.4
Orimulsion	140	1
LPG	110	24
OPG	110	1.1
Aviation Fuel (domestic)	170	50
Natural Gas	110	2.4
Colliery Methane	110	5
Lubricants	140	25
Biogas	110	5
Field burning	230	25
Wood	230	30
Straw	230	50

1   Expressed as 2s/E
2   With 97.5 percentile 100 times the 2.5 percentile

The uncertainty distribution of the calculated emission was heavily skewed so that the 5th percentile was 45% of the mean and the 95th percentile 2.4 times the mean. This would suggest a mean emission of 181 kt in 1998 within a range of 81 kt to 421 kt.

4.5   HALOCARBONS AND SF6

The uncertainties in the emissions of HFCs, PFCs and SF6 were taken from Eggleston et al (1998). The uncertainties were estimated as 25% for HFCs, 19% for PFCs and 13% for SF6 in 1990.

4.6   GWP WEIGHTED EMISSIONS

The uncertainty in the combined GWP weighted emission of all the greenhouse gases in 1998 was estimated as 14% and in 1990, and 14% in 1998.

4.7 TIER 1 ESTIMATE OF UNCERTAINTIES

The IPCC Good Practice Guidance (IPCC, 2000) defines Tier 1 and Tier 2 approaches to estimating uncertainties in national greenhouse gas inventories. The Monte Carlo approach described above corresponds to Tier 2 whilst Tier 1 provides for a simplified calculation method based on the error propagation equations. The results of the Tier 1 approach are shown in Table A62. In the Tier 1 approach the emission sources are aggregated up to a level broadly similar to the IPCC Summary Table 7A. Uncertainties are then estimated for these categories. The uncertainties used in the Tier 2 approach are not exactly the same as those used in the Monte Carlo Simulation since the Tier 1 source categorisation is far less detailed. However, the values used were chosen to reflect the uncertainties used in the Monte Carlo Simulation. The Tier 2 approach is only able to model normal distributions. This presented a problem in how to estimate a normal distribution approximation of the lognormal distribution used for agricultural soils. The approach adopted was to use a normal distribution with the same mean as the lognormal distribution. The standard deviation was then estimated as (97.5 percentile − mean)/2.

The Tier 1 approach suggests an uncertainty of 17% in the combined GWP total emission. The analysis also estimates an uncertainty of 2% in the trend between 1990 and 1998.

Table A62: Tier 1 Uncertainty Analysis

Source Category	Gas	Base year emissions 1990	Year Y emissions 1998	Activity data uncertainty range	Emission factor uncertainty range	Combined uncertainty range as % of source category	Combined uncertainty range as % of national total in year y	Change in % difference between total national emissions in year y and the base year if source category emissions increased by 1% in the base year and in year y.	Change in % difference between total national emissions in year y and the base year if source category emissions increased by 1% in year y only	Uncertainty in trend in national emissions introduced by emission factor uncertainty assuming that emission factors are correlated between years	Uncertainty in trend in national emissions introduced by emission factor uncertainty assuming that activity data are not correlated between years
		Gg CO2 equiv	Gg CO2 equiv	%	%	%	%	Fraction	Fraction	%	%
A	B	C	D	E	F	G	H	I	J	K	L
Coal	CO2	237791	140309	1.2	6	6.118823	1.220096	-0.098097	0.181458	-0.588581	0.307944
Oil	CO2	208684	191795	2	2	2.828427	0.770947	0.002437	0.248044	0.004874	0.701574
Natural Gas	CO2	111052	189867	2.4	1	2.600000	0.701558	0.114688	0.245550	0.114688	0.833423
Other (waste)	CO2	139	866	7	20	21.189620	0.026083	0.000957	0.001120	0.019143	0.011089
Solid Fuel Transformation	CO2	3000	1707	1.2	6	6.118823	0.014841	-0.001324	0.002207	-0.007943	0.003746
Oil & Natural Gas	CO2	8908	6277	1	14	14.035669	0.125216	-0.002365	0.008118	-0.033105	0.011481
Cement Production	CO2	6693	6274	1	2	2.236068	0.019937	0.000237	0.008114	0.000473	0.011475
Lime Production	CO2	1192	1703	1	5	5.099020	0.012343	0.000800	0.002203	0.004002	0.003115
Limestone & Dolomite use	CO2	1369	1467	1	5	5.099020	0.010630	0.000285	0.001897	0.001427	0.002683
Soda Ash Use	CO2	165	154	15	2	15.132746	0.003313	0.000005	0.000199	0.000010	0.004226
Ammonia Production	CO2	1358	1111	10	1	10.049876	0.015861	-0.000162	0.001436	-0.000162	0.020311
Iron&Steel Production	CO2	3210	2150	1.2	6	6.118823	0.018700	-0.000997	0.002781	-0.005983	0.004720
Land Use Change & Forestry	CO2	31742	26512	1	53	53.009433	1.997286	-0.003069	0.034288	-0.162642	0.048490
MSW Incineration	CO2	659	0	7	20	21.189620	0.000000	-0.000776	0.000000	-0.015510	0.000000
	CO2 Total	615963	570192								
All Fuel	CH4	2508.079634	1982.122576	1.2	50	50.014398	0.140886	-0.000388	0.002563	-0.019416	0.004350
Coal Mining	CH4	17402.349	5702.973	1.2	13	13.055267	0.105810	-0.013102	0.007376	-0.170331	0.012517
Solid Fuel Transformation	CH4	0.530	0.193	1.2	50	50.014398	0.000014	0.000000	0.000000	-0.000019	0.000000
Natural Gas Transmission	CH4	8942.561	8018.709	1	15	15.033296	0.171317	-0.000154	0.010370	-0.002311	0.014666
Offshore Oil& Gas	CH4	2402.154	1767.646	1.2	28	28.017851	0.070384	-0.000541	0.002286	-0.015149	0.003233
Iron & Steel Production	CH4	16.361	13.279	1.2	50	50.014398	0.000944	-0.000002	0.000017	-0.000104	0.000029
Enteric Fermentation	CH4	19176.992	18533.506	0.1	20	20.000250	0.526786	0.001399	0.023969	0.027983	0.003390
Manure Management	CH4	2338.245	2352.004	0.1	30	30.000167	0.100277	0.000290	0.003042	0.008697	0.000430
Field Burning	CH4	266.045	0.000	25	50	55.901699	0.000000	-0.000313	0.000000	-0.015655	0.000000
Solid Waste Disposal	CH4	23457.000	16254.000	15	46	48.383882	1.117641	-0.006584	0.021021	-0.302849	0.445920
Wastewater Handling	CH4	701.022	728.710	1	50	50.009999	0.051791	0.000117	0.000942	0.005869	0.001333
Waste Incineration	CH4	0.654	0.663	7	50	50.487622	0.000048	0.000000	0.000001	0.000004	0.000008
	CH4 total	77212	55354								

Table A62: Tier 1 Uncertainty Analysis (Continued)

Source Category	Gas	Base year emissions 1990	Year Y emissions 1998	Activity data uncertainty range	Emission factor uncertainty range	Combined uncertainty range as % of source category	Combined uncertainty range as % of national total in year y	Change in % difference between total national emissions in year y and the base year if source category emissions increased by 1% in the base year and in year y.	Change in % difference between total national emissions in year y and the base year if source category emissions increased by 1% in year y only	Uncertainty in trend in national emissions introduced by emission factor uncertainty assuming that emission factors are correlated between years	Uncertainty in trend in national emissions introduced by emission factor uncertainty assuming that activity data are not correlated between years
		Gg CO2 equiv	Gg CO2 equiv	%	%	%	%	Fraction	Fraction	%	%
A	B	C	D	E	F	G	H	I	J	K	L
Other Combustion	N2O	3855.187	3619.030	1.2	195	195.003692	1.002944	0.000143	0.004680	0.027928	0.007943
Transport	N2O	1300.439	4109.044	1.4	170	170.005765	0.992764	0.003784	0.005314	0.643207	0.010521
Oil & Natural Gas	N2O	3.015	2.261	1	110	110.004545	0.000354	-0.000001	0.000003	-0.000069	0.000004
Adipic Acid Production	N2O	25136.353	14965.560	0.5	15	15.008331	0.319203	-0.010225	0.019355	-0.153376	0.013686
Nitric Acid Production	N2O	3970.076	3441.211	10	230	230.217289	1.125877	-0.000222	0.004450	-0.051047	0.062939
Iron & Steel	N2O	11.106	9.148	1.2	118	118.006102	0.001534	-0.000001	0.000012	-0.000146	0.000020
Manure Management	N2O	1582.763	1542.951	1	412	412.001214	0.903425	0.000133	0.001995	0.054673	0.002822
Agricultural Soils	N2O	29472.041	28130.299	1	412	412.001214	16.470789	0.001694	0.036380	0.697881	0.051449
Field Burning	N2O	77.762	0.000	25	230	231.354706	0.000000	-0.000092	0.000000	-0.021049	0.000000
Wastewater Handling	N2O	153.458	157.925	0.01	230	230.000000	0.051620	0.000024	0.000204	0.005436	0.000003
Waste Incineration	N2O	115.215	5.700	7	230	230.106497	0.001864	-0.000128	0.000007	-0.029492	0.000073
	N2O Total	65677	55983								
Industrial Processes	HFC	11374	20183	1	25	25.019992	0.717639	0.012714	0.026102	0.317848	0.036913
Industrial Processes	PFC	2281	652	1	19	19.026298	0.017623	-0.001842	0.000843	-0.034990	0.001192
Industrial Processes	SF6	724	1289	1	13	13.038405	0.023891	0.000815	0.001667	0.010597	0.002358
	Halocarbon & SF6 Total	14379	22124								
TOTALS GWP		773231	703653								
Total Uncertainties%							16.9				

5 The IPCC Reference Approach

5.1 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.

5.2 ACTIVITY DATA

The activity data are taken from DTI (1999) and is consistent with the categories listed in the IPCC Reference Approach. In order to improve the estimates, coal data were disaggregated into anthracite, coking coal and other bituminous coal, though for anthracite and coking coal, only imports, exports and consumption data were available.

The energy consumption in TJ (net) was calculated using gross calorific data for the fuels taken from DTI, (1999) and the conversion factors discussed in Section 3.2.1. Where suitable data were unavailable, defaults from IPCC (1997) were used. There have been some retrospective revisions in the calorific values used for coal based on DTI (1999). Also time series data for the GCV of fuels were used rather than an average figure for all years.

5.3 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).

5.4 CARBON STORED IN PRODUCTS

The carbon stored in products was calculated according to IPCC (1997b) using data from DTI (1998). 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 Section 3.12.7). It is now assumed that 40% of lubricants are burnt as fuel, DTI (1999).

5.5   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 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 1- 4 % 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, 1999), 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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