

Appendix 3

Energy (Fugitive Emissions)

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1 Introduction

This Appendix outlines the emissions of greenhouse gases arising from the production, extraction of coal, oil and natural gas, their storage, processing and distribution. These emissions are fugitive emissions and are reported in IPCC Table 1B. Emissions from fuel combustion during these processes are reported in IPCC Table 1A and are described in Appendix 2. In certain cases the methodology of some of these fuel combustion emissions are discussed in this Appendix, because they have links with the methodologies used for fugitive emissions.

2 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 saleable coal production statistics reported in DTI, (2000). 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. The distinction was sufficiently marked to allow the use of a separate emission factor. 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 1.

Table 1 Methane Emission Factors for Coal Mining (kg/t coal)

	1990	1991	1992	1993-97	1998	1999
Deep Mined	10.1 ^a	10.3 ^a	11.1 ^a	13.4 ^b	13.4 ^c	13.5 ^c
Coal Storage & Transport ^a	1.16	1.16	1.16	1.16	1.16	1.16
Licensed Mine ^d	1.36	1.36	1.36	1.36	-	-
Open Cast ^d	0.34	0.34	0.34	0.34	0.34	0.34

a Bennet *et al* (1995)

b Value for 1998 assumed

c Estimated factor based on RJB (2000) data.

d Williams (1993)

The licensed and open cast factors are taken from Williams (1993). The deep mined factors for 1990 -1992 and the coal storage factor are taken from Bennet *et al* (1995). This was a study on deep mines which produced estimates of emissions for the period 1990-93. This was a period over which mines were being closed, hence the variation in emission factors. The emission factors for 1998-99 are based on operator's measurements of the methane extracted by the mine ventilation systems. The mines surveyed cover around 90% of deep mined production. No time dependent data are available for 1993-97, so the 1998 factor was used. Methane extracted is either emitted to atmosphere or utilized for energy production. Methane is not flared for

safety reasons. The factors reported in Table 1 refer to emissions and exclude the methane utilised. The coal storage and transport factor is only applied to deep mined coal production.

The activity data for the coal mining emissions are reported in the CRF tables attached as a CD ROM to this report. It should be noted that the number of active deep mines reported is defined as the number of mines producing at any one time during the period. (Coal Authority, 2000). Hence, this would include large mines as well as small ones or those that only produced for part of the year. The data supplied in previous inventories, were the number of major sites operating. The colliery methane utilization data are taken from DTI (2000).

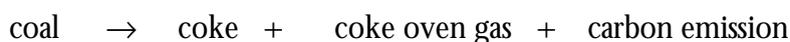
These estimates only include emissions from working mines and exclude closed mines. It was previously believed that emissions became negligible once a coal mine closed, particularly if the mine flooded (Williams, 1993). However, a recent review sponsored by DETR, suggests that these emissions may be significant. (Sage, 2001). A number of estimates have been made ranging from 20 to 300 kt methane in 1999. More research is required to obtain a reliable estimate.

3 Solid Fuel Transformation

This section discusses fugitive emissions from solid fuel transformation processes. These emissions are reported in IPCC category 1B1b. The IPCC Revised 1996 Guidelines do not provide any methodology for such estimates, hence emissions are largely based on default emission factors and the need to avoid double counting CO₂ emissions. Combustion emissions from these processes are discussed in Appendix 2.

3.1 COKE PRODUCTION

In a coke oven, coal is transformed into coke and coke oven gas. The coke oven gas is used as a fuel to heat the coke oven or elsewhere on the site. The coke may be used elsewhere as a fuel or a reducing agent in metallurgical processes. A carbon balance is performed over the coke oven on the carbon contents of the fuels input and the fuels produced based on the scheme.



The emission of carbon from coke production is:

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

where

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

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	
E(p,s,f)	=	Emission of pollutant from source s from fuel f.	

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

In reality the carbon emission is in the form of coke oven gas, coal tars used as fuel that are 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.

Process emissions of other pollutants from coke ovens are estimated either on the basis of total production of coke or the coal consumed. The emission factors used are given in Table 2.

3.2 SOLID SMOKELESS FUEL PRODUCTION

For solid smokeless fuel production the process is assumed to be:



The emission of carbon from SSF production is:

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

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	
ck	=	coke	

The carbon contents of coking coal and ssf 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 2 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. There are a number of processes used in the UK ranging from processes similar to coking to bricquetting anthracite dust. Given the number of processes in use these estimates will be very uncertain.

Data are available on the production of SSF and the fuels used (DTI, 2000), however it is clear that in recent years both coke and imported petroleum coke have 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 it is assumed that 100 kt *per annum* of petroleum coke was used in SSF production since 1992 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 2 Emission Factors Used for Coke and Solid Smokeless Fuel Production

	Units	CH ₄	CO	NO _x	SO ₂	NMVOC
Coke	kt/Mt coke made	0.081 ^a	4.6 ^b	-	-	0.018 ^a
Coke	kt/Mt coal consumed	-	-	0.04 ^b	0.02 ^b	-
SSF	kt/Mt SSF made	0.081 ^a	-	-	-	0.018 ^a
SSF	kt/Mt coal consumed	-	0.6 ^b	0.01 ^b	0.44	-

a EIPPCB, (2000)

b USEPA (2000)

4 Oil and Natural Gas

The emissions estimates for the offshore industry are based on the UKOOA sponsored SCOPEC Inventory (SCOPEC, 2000). This is a detailed inventory based on returns from the operating companies for the years 1995-1999. For years prior to 1995 the estimates are based on the UKOOA study for 1991 (UKOOA, 1993). This source 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 pertain to the offshore platforms and onshore terminals on the UK Continental Shelf Area and represented by UKOOA.

UKOOA have produced guidelines for estimating and reporting emissions. (E&P Forum, (1994), UKOOA (1995)). The operators are required to report flaring and venting volumes and compositions. Methodologies have been developed to estimate combustion emissions from turbines, boilers and heaters and fugitive emissions. These can be calculated on a plant item by item basis. Where detailed data are not provided estimates are made on the basis of oil and gas throughput. However, the proportion of emissions estimated on throughput has fallen and in the 1999 inventory, no estimates were made in this way.

The data reported in the SCOPEC database must be reconciled with the UK Energy Statistics and integrated into the NAEI without double counting emissions. The data available only cover 1995-99 and 1991 and must be extrapolated to other years to produce a time series. The diesel oil consumption by offshore installations is not reported separately in the UK Energy Statistics 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, offshore emissions are estimated in the following categories each with its own methodology:

- Offshore flaring
- Offshore Oil & Gas (well testing)
- Offshore Oil & Gas (venting)
- Offshore Oil & Gas
- Offshore Loading
- Onshore loading
- Storage
- Offshore own gas use (reported under 1A1c Other Energy Industries)
- Gas Separation Plant (reported under 1A1c Other Energy Industries)

The mapping of these sources to IPCC categories is described in Appendix 1. Activity data are reported in the CRF Background Table 1B2, however in most cases these data are not used to calculate the emissions, but is provided for comparison with other inventories.

4.1 OFFSHORE FLARING

This includes flaring from offshore platforms and onshore terminals. Flaring emission data for CO₂, SO₂, NO_x, CO, NMVOC, N₂O and methane were taken from the SCOPEC (1999) and UKOOA (1993) studies for 1995-1999 and 1991 respectively. These emissions were extrapolated to other years using the data on flaring volumes reported in DTI (2000). This involved calculating aggregate emission factors (kt pollutant /Mm³ gas flared). The SCOPEC estimates were used for 1995-1999 and the UKOOA estimate for 1990-1994. The aggregate emission factors are given in Table 3. Emissions of nitrous oxide were estimated using a factor of 0.000088 kt/Mm³ based on SCOPEC (1999).

The UKOOA/SCOPEC data do not include flaring on onshore oil production fields. These emissions are added based on data collected by DTI (2000a) and the offshore flaring factors. The contribution is very small.

Table 3 Aggregate Emission Factors for Flaring (kt/Mm³)

	C	SO ₂	NO _x	CO	NMVOC	CH ₄
1999	0.619	0.00158	0.00108	0.00586	0.00670	0.00916
1998	0.728	0.00038	0.00154	0.00816	0.00887	0.0106
1997	0.731	0.00043	0.00162	0.00844	0.00942	0.0105
1996	0.725	0.00002	0.00159	0.00864	0.00972	0.0115
1995	0.757	0.00009	0.00201	0.00932	0.01111	0.0129
1990-94	0.738	0.00012	0.00140	0.00982	0.0105	0.0075

Flaring is reported under 1B2ciii 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. This is based on estimates supplied by UKPIA (2000).

4.2 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 CO₂, SO₂, NO_x, CO, NMVOC, N₂O and methane were taken from the SCOPEC (2000) and UKOOA (1993) studies for 1995-1999 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 fuel gas consumption by the offshore industry reported in DTI (2000). The DUKES category 'producers own use' is mostly if not wholly natural gas used on offshore installations for running turbines, engines, heaters and boilers. The DUKES category oil and gas extraction refers to ethane, propane and butane used in gas separation plants at oil terminals. It is now clear that the fuel gas emissions reported by SCOPEC include methane and natural gas liquids, hence it correct to match these emissions with the natural gas, ethane, propane and butane data reported in DTI (2000). This involved calculating aggregate emission factors (kt pollutant /Mtherm) for fuel gas defined as natural gas, LPG (butane and propane) and OPG (ethane). The SCOPEC estimates were used for 1995-1999 and the UKOOA estimate for 1990-1994. The aggregate emission factors are given in Table 4.

Table 4 Aggregate Emission Factors for Fuel Gas Use. (kt/Mtherm)

	C	SO ₂	NO _x	CO	NMVOC	CH ₄
1999	1.865	0.00175	0.0177	0.0073	0.00028	0.00326
1998	1.887	0.00038	0.0164	0.0063	0.0002	0.0012
1997	1.891	0.00133	0.0171	0.0067	0.00024	0.00157
1996	1.928	0.000049	0.0178	0.0065	0.00023	0.00135
1995	1.940	0.00032	0.0203	0.0075	0.00020	0.00158
1990-94	1.690	0.00034	0.0344	0.0061	0.0014	0.00085

Emissions of nitrous oxide were estimated using a factor of 0.000516 kt/Mtherm fuel gas based on SCOPEC (1999). These emission factors apply to the mixture of methane, ethane, propane and butane used. In the NAEI database they are applied to the categories:

- Offshore own gas use: natural gas
- Gas separation plant: LPG
- Gas separation plant: OPG

Emissions are reported under 1A1cii Other Energy Industries.

In previous inventories, it was assumed that the propane, butane and ethane consumption pertained to refineries rather than terminals. This assumption resulted in a double count, which has now been removed.

4.3 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 CO₂, SO₂, NO_x, CO, NMVOC and methane were taken from the SCOPEC (2000) 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 1995-1999 and 1991 were extrapolated to other years using data on the numbers of wells explored, reported in DTI (2000b). 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 1995-1999 with the 1995 factor used for all previous years. The aggregate emission factors are given in Table 5. Well testing is reported under 1B2a Oil Production since many of the wells produce oil and gas.

Table 5 Aggregate Emission Factors for Well Testing.(kt/well explored)

	C	SO ₂	NO _x	CO	NMVOC	CH ₄
1999	3.61	0.00006	0.011	0.0558	0.0685	0.0151
1998	3.73	0.131	0.012	0.0619	0.0656	0.016
1997	2.78	0.104	0.009	0.0461	0.0519	0.0121
1996	2.34	0.092	0.008	0.0411	0.0462	0.0108
1995	2.69	0.1	0.0087	0.0445	0.0759	0.0117
1990-94	2.69	0.1	0.0087	0.0445	0.0759	0.0117

4.4 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 from storage of crude oil at terminals. The approach adopted was determined by the data available. For the years 1995-1999, detailed estimates from the SCOPEC (2000) survey were used.

For the years 1990-1992 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 Sections 3.1 and 3.2 were subtracted. The emissions for the years 1993 and 1994 were then estimated by interpolation.

Other emissions from platforms and terminals are reported in the NAEI category offshore oil & gas, and are mapped onto 1B2 a Oil ii Production. It is not possible to split oil and gas production emissions since oil and gas are frequently produced on the same platform. From 1995 onwards, the offshore oil & gas category contains emissions of fugitives and processes only. Venting and storage are reported in their respective categories.

Table 6 Aggregate Emission Factors used for Emissions from Platforms and Terminals

	Period	Units	CH ₄	NM VOC
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

4.5 LOADING EMISSIONS

Emissions from tanker loading and unloading were taken from the SCOPEC (1999) study for 1995-99. They are based on the tonnage of oil shipped and site specific emission factors, which account for recently applied abatement measures. A correction is made to add on the emissions from the Seal Sands Refinery, which is only included in the recent SCOPEC Inventories. These data were provided by the operator. (Philips Imperial Petroleum, 2000). 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 specific to terminals for onshore loading. Table 7 shows aggregate factors calculated from the amounts of oil loaded.

Table 7 Aggregate Emission Factors used for Emissions Loading and Unloading

	Period	Units	CH ₄	NM VOC
Offshore Loading	1999	t/kt oil	0.074	1.34
	1998		0.043	1.44
	1997		0.036	1.98
	1996		0.035	1.96
	1990-95		0.036	2
Onshore Loading	1999	t/kt oil	0.0064	0.69
	1998		0.013	0.79
	1997		0.003	0.78
	1996		0.015	0.8
	1990		0.013	0.73

4.6 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 the 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 (British Gas, 1993, Transco, 2000). The emissions for 1997-99 are

based on the results of a new model (Transco 2000) which reflects recent conditions in the gas industry more accurately and supercedes the earlier model. The emissions from 1990-96 are based on the British Gas model which provided historical data for 1991-94 but projected estimates for 1995-96. The estimates of the new model were used to replace the old model estimates for 1997-98 and are slightly higher. The composition of natural gas assumed for 1990-96 is 91.6% w/w methane (British Gas, 1999) and that assumed for 1997-99 is 88.18% w/w methane, Transco (2000). An extra emission of 40 kt methane has been included to account for high-pressure mains which were not included in the British Gas and Transco models. (DETR, 1999)

4.7 PETROL DISTRIBUTION

The NAEI reports emissions from the following categories:

- Petrol Stations (Petrol Delivery)
- Petrol Stations (Vehicle Refueling)
- Petrol Stations (Storage Tanks)
- Petrol Stations (Spillages)
- Petrol Terminals (Storage)
- Petrol Terminals (Tanker Loading)
- Refineries (Road/Rail Loading)

These cover evaporative losses of NMVOCs from the various stages from refinery dispatch to sale. They are mapped onto 1B2a Distribution of Oil Products. The terminal (storage) estimates are based on standard industry calculation procedures reported in CONCAWE (1986). The remaining emissions are based on factors supplied by the Institute of Petroleum (2000) for the loading and storage technologies involved. A correction is applied for the changes in volatility and density of petrol over the time period. The activity data are the sales of leaded and unleaded petrol taken from DTI (2000).

4.8 REFINERIES AND PROCESSES

The IPCC category 1B2aiv Refining and Storage reports estimates of NMVOC emissions from oil refineries. In the NAEI these are split into:

- Refineries (drainage)
- Refineries (tankage)
- Refineries (Process)
- Petroleum Processes

All are based on UKPIA (2000) estimates for 1993-99. Prior to this period the 1993 value is used for drainage and tankage. Process emissions are extrapolated based on oil throughput.

The NAEI category Petroleum Processes reports NMVOC emissions from certain petroleum processes such as specialist refining, bitumen refining and onshore oil fields. The data are taken from the pollution inventory (Environment Agency, 2000). Prior to 1994 the estimates are extrapolated, based on refinery capacity and onshore oil throughput.

The NAEI also reports emissions from gasification processes. These arise from certain gas treatment processes that occur downstream of the gas terminals and are not included in the SCOPEC Inventory. They are taken from the pollution Inventory (Environment Agency, 2000). For the years prior to 1994 They are extrapolated based on gas throughput. Care is taken to avoid double counting with the offshore emissions.

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Appendix 4

Industrial Processes and Solvents

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1 Cement Production

1.1 PROCESS EMISSIONS

In a cement kiln, calcium carbonate (CaCO_3) is broken down to CaO and carbon dioxide. The methodology used pertains to the IPCC Tier 2 approach (IPCC, 2000). The emission was estimated from the annual UK production of clinker (DETR, 2000) and the IPCC default emission factor of 138.3 t C/ kt clinker produced (IPCC, 1997). So far it has not proved possible to obtain data on the CaO content of clinker either on a national basis or a site basis so a default is used. A revision included in the 1999 Inventory is to correct for the loss of cement kiln dust and here the default of 2% is used (IPCC, 2000). Hence the corrected emission factor is 141.1 t C/ kt clinker. 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. Clinker consumption data are reported in the CRF Tables attached to this report as a CD ROM.

1.2 COMBUSTION EMISSIONS

Section 1.1 describes the emission of CO_2 from the degradation of limestone used in cement manufacture. The NAEI category cement (fuel combustion) covers emissions of CO_2 , methane and N_2O arising from the combustion of fuels in kilns. Emission factors are shown in Table 1. In DUKES (DTI, 2000), this fuel consumption is included under 'industry'. Fuel estimates were derived from Blyth *et al* (1996) and British Cement Association (1998). The BCA data supplied an estimate of total kiln fuel in 1998 and the Blyth *et al* study gave a break down by fuel type used in cement and plaster production for 1993. Using these data and extrapolating to other years by using clinker production data (DETR, 2000), an approximate time series for cement coal, oil, petroleum coke and gas consumption was developed. Having estimated the consumption of coal, fuel oil and natural gas by the cement sector, the fuel consumption by other industry was adjusted so that the total consumption agreed with DUKES (DTI, 2000). Estimates were also made of emissions from the combustion of scrap tyres and waste oils in cement kilns. The scrap tyre data were taken from Collingwood (1997) and DTI (2000a). The consumption of waste oils is uncertain. Some estimates for 1994-95 are available (Collingwood, 1997) but for subsequent years we used the advice from BCA that the consumption of wastes as fuel was no more than 6%. (British Cement Association, 2000).

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 reported in Ogilvie, (1995).

For the pollutants NO_x , CO, NMVOC and SO_2 , estimates were based on the site emissions for cement plant reported by the Environment Agency (2000). The aggregate factors were calculated based on estimated plant capacities supplied by British Cement Association (2000).

They are expressed in terms of the emission per tonne of clinker produced. And are shown in Table 2.

Table 1: Emission Factors for Cement Kilns based on Fuel Consumption

	CO ₂ ^a	CH ₄	N ₂ O	Units
Coal	659.6 ^b	0.3 ^g	0.1084 ^j	kt/Mt fuel
Fuel Oil	850 ^c	0.0406 ^h	NE	kt/Mt fuel
Natural Gas	1501 ^d	0.1045 ^h	NE	g/therm
Petro-Coke	800 ^c	0.346 ^h	0.1302 ^j	kt/Mt fuel
Scrap Tyres	757 ^e	0.0258 ^g	NE	kt/Mt fuel
Waste Oils	859 ^f	0.0406 ⁱ	NE	kt/Mt fuel

a Emission as carbon

b British Coal (1989)

c UKPIA (1989)

d British Gas (1992)

e Based on Ogilvie (1995)

f As gas oil (UKPIA, 1989)

g Brain *et al* (1994)

h EMEP/CORINAIR (1996)

i CORINAIR (1992)

j Fynes *et al* (1994)

Table 2: Emission Factors for Cement Kilns based on Clinker Production

	CO	NO _x	NMVOG	SO ₂	Units
Cement	2.62	3.43	0.105	2.44	kt/Mt Clinker

2 Lime Production

Lime (CaO) is manufactured from limestone (CaCO₃) and dolomite (CaCO₃MgCO₃) by heating in a limekiln resulting in the evolution of carbon dioxide. The UK does not use the IPCC methodology (IPCC, 2000) which is based on lime production, because limestone and dolomite consumption data are available (BGS, 2001). The use of consumption data is simpler and probably more reliable since it is not necessary to consider the different types of lime produced. 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 the Solvay process uses a large proportion of this in the production of sodium carbonate. The limestone is calcined to produce carbon dioxide but nearly all this is recovered and is sequestered in the sodium carbonate produced. Also the calcination of limestone in the sugar industry is excluded. This is because, the lime produced is used in sugar refining and the overall process does not result in a net emission of carbon dioxide. Limestone consumption data are reported in the CRF Tables attached to this report as a CD ROM.

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
- liming of soils (see Appendix 6)

Usage data are available in BGS (2001) and ISSB (2000) 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 CO₂ Emissions and Removals from Soils.

4 Soda Ash Use

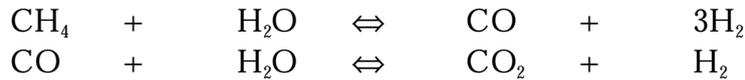
Emissions of CO₂ from soda ash (sodium carbonate) production are not specifically identified. However, the emissions arise from fuel combustion used in the Solvay process and should be included elsewhere under industrial combustion. Some of the uses of sodium carbonate produced result in the emission of CO₂ (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, 2000). This is around 15% of the mass of glass produced. An emission factor of 113 kt C/ Mt soda ash is used. The estimates include both container and flat glass.

5 Asphalt Consumption

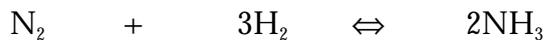
The inventory reports emissions of NMVOCs from asphalt paving and road construction. The emission estimates are based on consumption data of bitumen emulsions, cut-back bitumen and cut-back fluxes. The emission factors used are 7, 87.5 and 700 kg/t for each component respectively. The Bitumen Association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

6 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:



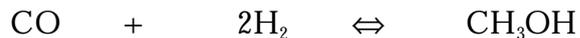
The hydrogen is then reacted with nitrogen from air to form ammonia



If there is no use of the by-products CO and CO₂ formed then these are emitted to atmosphere. The carbon monoxide is usually oxidised so the CO₂ emission can be estimated from the natural gas usage or the amount of ammonia produced. The emission is 0.97 t CO₂ /t NH₃ 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 sequestered as methanol and is not emitted to atmosphere.

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



so that all the carbon content of the natural gas is sequestered as methanol.

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

Two estimates were made:

- The amount of CO₂ 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- CO₂ pollutants.

The procedure adopted to estimate the emission of CO₂ from ammonia manufacture was:

1. Data on the plant capacity, natural gas consumption or CO₂ emission from ammonia plant, acetic acid plant and methanol plant were collected from manufacturers. This included an

approximate 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 CO₂ emission from ammonia manufacture was calculated

The total feedstock use of natural gas was estimated as the sum of items 1-3. It is known that some of the CO₂ produced is recovered and sold for use in the food industry and nuclear industry. Because all this carbon dioxide is eventually emitted, the estimates are compiled including sales. This procedure will be more reliable than trying to identify the end use of the carbon dioxide particularly as some carbon dioxide used in the food industry arises from fermentation.

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.

Terra Nitrogen, Kemira, ICI and BP Chemicals supplied the necessary data.

7 Nitric Acid Production

The manufacture of nitric acid produces emissions of both NO_x and nitrous oxide. All plant operators were able to supply data on nitrous oxide emissions and production for 1999. For previous years, emissions were calculated for each plant by extrapolating the 1999 emission (or in some cases 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. The default emission factor was 6kt/Mt 100% acid produced. This is an average factor based the range quoted in IPCC Guidelines (IPCC, 1997) for medium pressure plant. 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. In the period 1990 to 1993, two other plants were known to operate however these have now closed down. Their emissions are estimated based on plant capacity

and the default emission factor. Some nitric acid capacity is associated with the adipic acid plant. From 1990-1993, its emissions are reported combined with the adipic acid plant emissions.

Table 3 Summary of Nitric Acid Production in UK

	1990	1994	1995	1996	1997	1998	1999
No of Sites	8	6	6	6	6	6	6
Production/capacity Mt 100% Nitric Acid	2.41	2.43	2.40	2.44	2.35	2.61	2.44
Aggregate Emission Factor kt N ₂ O/Mt	5.54	5.71	4.14	4.19	4.12	4.27	3.95
Aggregate Emission Factor kt NO _x /Mt	3.0	1.93	0.808	0.743	0.902	0.790	0.947

Table 3 summarizes production data and gives the aggregate emission factor. The data for 1990 exclude the contribution of the nitric acid plant associated with the adipic acid plant. The production data are a mixture of precise production data and plant capacity. The emissions are based on the data reported by the operators and consequently the emission factors they have agreed to use with the Environment Agency. These do vary between plant but all are within the range reported in IPCC (2000). The variation in the aggregate factor is due to:

- varying production levels of individual plant
- installation of an abatement system on a plant in 1996
- plant closures

The number of sites is reported, as this is fairly unambiguous. In practice there may be more than one plant on a site or a plant may be composed of one or more identical units.

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).

For 1994 onwards estimates of NO_x are based on returns from manufacturers. Emissions from 1990 to 1993 were estimated by linear interpolation. Aggregate emission factors are reported in Table 3.

8 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, 2000). The estimates are based on an emission factor of 0.3 kt N₂O/Mt adipic acid produced. 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. In 1998 an N₂O abatement system was retrofitted to the plant. This has resulted in a 96% reduction in emissions in 1999. Emissions, destruction and activity data are reported in the CRF tables attached to this report on a CD ROM.

9 Other Chemical Industry

Emissions of methane from the chemical industry are reported under 2B5. The emission is the sum of all emissions of methane from chemical processes reported in the Pollution Inventory (Environment Agency, 2000). The Pollution Inventory does not fully identify the processes by type, hence it is not possible to disaggregate the emission by process. Also, activity data are not available for the sources listed in the IPCC Guidelines. Hence the total emission is reported for all years. It is expected that the detail of these estimates will be improved in future.

Emissions of NMVOC, reported for the organic chemical industry are based on the Pollution Inventory (Environment Agency, 2000). For the years prior to 1994 for which data are unavailable, they are extrapolated using an index of production for the Chemical Industry (ONS, 2000). Also included is an emission from ship purging. This is an emission arising from the cleaning of ships tanks for carrying chemicals, where contamination must be avoided. The estimate is a single figure for all years taken from Rudd *et al* (1996).

Emissions of sulphur dioxide from sulphuric acid production are based on detailed manufacturers' returns compiled by NSSA (2000). An emission of SO₂ from the chemical process to produce pigments is also reported in this category based on Environment Agency (2000).

10 Iron and Steel

The following emissions are reported under 2C1 Iron and Steel Production.

- Iron and Steel Blast Furnaces: CO₂ and other process emissions
- Flaring of blast furnace gas
- Electric Arc Furnaces
- Basic Oxygen Furnaces.

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 and are discussed in Section 3.

10.1 CARBON DIOXIDE EMISSIONS

The IPCC Good Practice Guidelines Tier 2 methodology considers a two-stage carbon balance on

1. Iron making
2. Steel making

The UK methodology considers the processes as a single operation

coke → blast furnace gas + carbon sequestered in steel +
carbon emission

This approach is equivalent to the IPCC approach because virtually all the iron produced in blast furnaces is used as a feedstock for steel making. Hence it is not necessary to consider the carbon sequestered in the iron separately. The UK approach also considers the carbon emitted in the form of blast furnace gas. Blast furnace gas is used as a fuel for heating blast furnaces and for electricity generation. The emissions from the combustion of blast furnace gas are reported under 1A2a Iron and Steel in the energy tables, hence it is necessary to account for this in the carbon balance to avoid double counting.

Hence by estimating the carbon content of the coke consumed and the blast furnace gas produced, the carbon emission from the iron and steel furnaces can be estimated as:

$$\begin{aligned}
 E(\text{car,I\&S BF,ck}) &= A(\text{I\&S BF,ck}) \times e(\text{car,I\&S BF,ck}) \\
 &\quad - E(\text{car,coke prod,bfg}) \\
 &\quad - E(\text{car,I\&S,bfg}) \\
 &\quad - E(\text{car,I\&S BF,bfg}) \\
 &\quad - E(\text{car,flaring,bfg}) \\
 &\quad - A(\text{I\&S BF,steel made}) \times e(\text{car,I\&S BF, steel made})
 \end{aligned}$$

where

$A(\text{I\&S B F,ck})$	=	Blast furnaces coke consumption	(kg)
$A(\text{I\&S BF,steel made})$	=	Crude steel production	(kg)
$e(\text{car,I\&S BF, steel made})$	=	Carbon content of steel made	(kg/kg)
$e(\text{car,I\&S BF,ck})$	=	Carbon content of coke	(kg/kg)
bfg	=	Blast Furnace Gas	
$E(\text{p,s,f})$	=	Emission of pollutant p from source s from combustion of fuel f	

The final term in the equation is the carbon sequestered in the steel produced. It is assumed that the carbon content of steel is around 1.7 kt C/Mt crude steel (BISPA, 1997). This is a very approximate estimate but the carbon sequestered is very small compared with the other terms. Other carbon contents are 820 kg C/kg for coke and 6.273 kg C/therm for blast furnace gas.

10.2 OTHER POLLUTANTS

Emissions from blast furnaces of other pollutants are estimated based on the methodology described in IPCC (1997) 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 4. Data on steel production are reported in ISSB (2000).

Table 4 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

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 EMEP/CORINAIR (1999) chapter on electric arc furnaces. The CO₂ emission arises from the consumption of a graphite anode and is based on manufacturer's data. The emission factors are reported in Table 5.

Environment Agency (2000) has reported large emissions of carbon monoxide from iron and steel processes. Their precise sources are not identified but we were advised that the main sources were sinter plant and basic oxygen furnaces (BOF). The reported emissions 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 in Appendix 1.

Table 5: Emission Factors for Electric Arc and Basic Oxygen Furnaces

	CO ₂ ^a	CH ₄ ^b	N ₂ O ^b	NO _x ^c	SO ₂ ^c	NMVOC ^c	CO ^c	Units
EAF	3.6	0.01	0.005	0.58	0.462	0.033	2.57	kt/Mt Steel
BOF	IE	NE	NE	NE	IE	NE	25.5 ^d	kt/Mt Steel

a BISPA (1997)

b EMEP/CORINAIR(1999)

c Emission factor for 1999 based on Environment Agency (2000)

d Emission factor estimated for emission reported in Pollution Inventory (Environment Agency, 2000) for sinter plant and BOF

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 (2000).

There is insufficient activity or emission factor data to make an estimate for emissions from ferroalloys. Emissions of CO₂ will be included in 2C1, since the fuels used as reducing agents are included in the energy statistics.

11 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 CO₂, SO₂ 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 6. The carbon emission factors reflect current practice, and higher emission factors were used for earlier years. For the other pollutants, emission factors are available for anode baking as well as production.

Table 6 Emission Factors for Aluminium Production

	Units	CO ₂ ^a	SO ₂ ^b	NO _x ^b	CO ^b
Soderberg	kt/Mt Al	520	14.2	0.93	74.2
Prebake	kt/Mt Al	420			
Anode Baking	kt/Mt anode	IE	1.07	0.63	5.27

a CO₂ as carbon, Alcan (1997).

b Alcan (2000)

Emissions of PFCs from aluminium production are based on manufacturers' emission estimates for 1990-97 and projections assuming improvements in control measures for 1998-99 (MCG, 1999).

12 Other Non-Ferrous Metals

Emissions of carbon monoxide for a number of non-ferrous metal production processes are reported under 2C5 Other. These are emissions reported in the Pollution Inventory (Environment Agency, 2000). They arise from secondary copper, secondary lead and various other non-ferrous metal production processes. A time series is estimated by extrapolating with an index of production for the non-ferrous metal industries (ONS, 2000). The emissions arise from the use of coke in these processes. Since the coke consumption data reported for iron and steel furnaces contains a contribution from non-ferrous metals, it is correct to match these emissions with that coke.

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 most are taken from EMEP/CORINAIR (1996). Activity data for food and drink were taken from ONS (2000) and data on whiskey production were taken from SWA (2000). Bread production data are

based on estimates for 1988-1992 published in DTI (1992) which have been extrapolated to other years on the basis of population (ONS, 2000).

Table 7: 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		1 ^a	kg/tonne
Meat, Fish & Poultry		0.3	kg/tonne
Sugar		1.557 ^b	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

a Federation of Bakers (2000)

b Environment Agency (2000)

14 Halocarbons and SF₆ Production

Emissions of HFCs, PFCs and SF₆ 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 14.1

14.1 CONSUMPTION OF HALOCARBONS AND SF₆

Emissions of HFCs, PFCs and SF₆ 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 SF₆ 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 use of SF₆ and PFC in the soles of some training shoes. When the shoes are disposed off an emission will occur. Electrical insulation is the leakage of SF₆ from circuit breakers used in high voltage electrical transmission. The estimates and the methodology used in their estimation are described in MCG (1999).

The approach adopted was to estimate the size of the bank of fluid held in products and equipment in each of the above list of sectors. Certain sectors (e.g. refrigeration, air conditioning, and foams) are broken down into subsectors. The bank of fluid is estimated by considering the consumption of fluid in each sector, together with corrections for imports, exports, disposal and emissions. Once the size of the bank in a given year is known, the emission can be estimated by application of a suitable emission factor. Emissions are also estimated from the production stage of the equipment and during disposal. The methodology corresponds to the IPCC Tier 2 'bottom up' approach. 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 were obtained from private companies on condition they are confidential. However, estimates of the total GWP of emissions in the main IPCC categories are provided.

14.2 POTENTIAL EMISSIONS OF HALOCARBONS AND SF₆

Potential emissions are in effect the apparent consumption of a fluid in a particular year. The IPCC (1997) 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. In the new inventory a revision has been made to the potential estimates. This involved correcting for the emissions from certain sectors since there is an assumption in the calculations that fluid leaking from the bank is replaced. Also data on disposals of fluid have now been included in the estimates. 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 (IPCC, 1997). The reporting of potential emissions is inapplicable to halocarbon manufacture and aluminium production though they were estimated for SF₆ 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 were 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.

15 Solvent and other Product Use

Appendix 1 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 CO₂ was estimated based on 1996 data and applied to all years. The CO₂ estimate is included as a footnote to IPCC Table 3 and is not included in the National Total.

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