Appendix 3
Energy (Fugitive Emissions)

CONTENTS

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 1B1ai Underground Mines-mining, 1B1ai Underground Mines-post-mining and 1B1aii Surface Mines respectively. Emissions are calculated from saleable coal production statistics reported in DTI, (2001). 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	2000
Deep Mined	10.1[a]	10.3[a]	11.1[a]	13.4[b]	13.4[c]	13.5[c]	14[c]
Coal Storage & Transport[a]	1.16	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	0.34

a Bennet *et al* (1995)
b Value for 1998 assumed
c Estimated factor based on RJB (2001) 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 1998-2000 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 series 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 utilized. 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, 2001). Hence, this would include large mines as well as small ones or those that only produced for part of the year. The colliery methane utilization data are taken from DTI (2001).

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 DEFRA, suggests that these emissions may be significant (Sage, 2001). The review discusses a number of estimates of closed mine emissions ranging from 20 to 300 kt methane in 1999. More research is planned with the aim of obtaining 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 CO_2 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 as 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:

$$\text{coal} \rightarrow \text{coke} + \text{coke oven gas} + \text{carbon emission}$$

The emission of carbon from coke production is:

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

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 p 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. Coke oven gas production and consumption data are reported in DTI (2001). A small proportion of this coke-oven gas is synthetic coke oven gas consisting of a mixture of blast furnace gas and natural gas. Since synthetic coke oven gas does not originate from coke ovens, it must be removed from the coke oven gas consumption data used in the mass balance calculation. This correction is small and results in an additional emission of 87 kt CO_2 in 2000.

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 (SSF) production the process is assumed to be:

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

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, SSF made and petroleum coke are 710 kgC/t, 790 kgC/t and 800 kg C/t respectively. In recent years DTI (2001) reports the coal consumed in these processes as anthracite. This reflects the trend away from the older coking type process towards the production of briquettes of powdered anthracite or petroleum coke. Hence, for 1996 onwards where DTI reports anthracite being used, a carbon content of 813 kg C/t is used

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 briquetting 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, 2001), 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 the Inventory, it is assumed that 100 kt *per annum* of petroleum coke were used in SSF production from 1992 to 1998 based on DETR (1998). For 1999-2000 approximate estimates by DTI (2001) were used. 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]	2.52[c]	-	1.02[c]	0.026[c]
Coke	kt/Mt coal consumed	-	-	0.02[b]		-
SSF	kt/Mt SSF made	0.081[a]	-	-	-	0.018[a]
SSF	kt/Mt coal consumed	-	0.3[b]	0.005[b]	1.07	-

a EIPPCB, (2000)
b USEPA (1997)
c Factor for 2000 based on Corus (2001) and Environment Agency (2001)

4 Oil and Natural Gas

The emissions estimates for the offshore industry are based on the UKOOA sponsored SCOPEC Inventory (SCOPEC, 2001). This is a detailed inventory based on returns from the operating companies for the years 1995-2000. 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 masses 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 and 2000 inventories, all estimates were based on detailed data. 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 1995-2000 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
- Oil Terminal Storage
- Offshore own gas use (reported under 1A1c Other Energy Industries)
- Gas Separation Plant (Combustion) (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 are provided for comparison with other inventories.

4.1 OFFSHORE FLARING

This includes flaring from offshore platforms and onshore terminals. Flaring emission data for CO_2, SO_2, NO_x, CO, NMVOC, N_2O and methane were taken from the SCOPEC (2001) and UKOOA (1993) studies for 1995-2000 and 1991 respectively. The SCOPEC estimates were used for 1995-2000 and an emission factor based on the UKOOA (1993) estimate for 1990-1994. The aggregate emission factors are given in Table 3 and the activity data in Table 4. The aggregate emission factors for 1995-2000 are reported as kg pollutant/kg gas flared and are calculated from the SCOPEC data. The UKOOA study for 1991 does not report activity data and so an aggregate factor was estimated using the flaring volume reported by DTI for 1991 and this factor applied for 1990 to 1994. Emissions for 1990-1994 were calculated using the DTI flaring volume data shown in Table 4. Emissions of nitrous oxide for the years 1990-1998 were estimated using a factor of 0.000088 kg/m^3 based on 1999 data.

The UKOOA/SCOPEC data do not include flaring on onshore oil production fields. These emissions are estimated by extrapolation using flaring volume data collected by DTI (2001a) and the offshore flaring factors. The onshore flaring data are shown in Table 4 though the contribution is very small.

Table 3 Aggregate Emission Factors for Flaring

	CO_2	CH_4	NO_x	CO	NMVOC	SO_2	N_2O	Units
2000	2.50	0.0108	0.00115	0.00637	0.00625	0.00099	0.000076	kg/kg
1999	2.66	0.0107	0.00127	0.00686	0.00784	0.00185	0.000103	kg/kg
1998	2.69	0.0107	0.00157	0.00836	0.00901	0.00033		kg/kg
1997	2.70	0.0107	0.00165	0.00866	0.00968	0.00040		kg/kg
1996	2.61	0.0104	0.0015	0.00870	0.00961	0.000017		kg/kg
1995	2.63	0.0102	0.00171	0.00871	0.00979	0.000088		kg/kg
1990-94	2.71	0.00778	0.00140	0.00982	0.0105	0.000122	0.000088	kg/m^3

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 (2001).

Table 4 Activity Data for Flaring

	Gas Flared (kt) SCOPEC [1]	Gas Flared, Offshore Fields & Terminals (Mm^3)[2]	Gas Flared, Onshore Fields (Mm^3)[2]
2000	1906	1814	15
1999	1880	2206	4.6
1998	2090[3]	2110	NE
1997	2098[3]	2122	7
1996	2571[3]	2539	15
1995	2509[3]	2388	11
1994	NE	3282	10
1993	NE	2461	16
1992	NE	2468	12
1991	NE	2531	7
1990	NE	2793	7

1 SCOPEC (2001)
2 DTI (2001) and previous editions.
3 A correction has been applied for non-reporting operators
NE Not Estimated

4.2 OFFSHORE 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, N_2O and methane were taken from the SCOPEC (2001) and UKOOA (1993) studies for 1995-2000 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 assumed to correspond with the fuel consumption of the offshore industry reported in DTI (2001). 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 is correct to match these emissions with the natural gas, ethane, propane and butane data reported in DTI (2001). The SCOPEC estimates were used for 1995-2000 and the UKOOA estimate for 1990-1994. . The aggregate emission factors are given in Table 5. The aggregate emission factors for 1995-2000 are reported as kg pollutant/ kg gas used and are calculated from the SCOPEC data. The UKOOA study for 1991 does not report activity data and so an aggregate factor was estimated using the offshore gas consumption reported by DTI for 1991 and this factor applied for 1990 to 1994. Emissions of nitrous oxide for the years 1990-1998 were estimated using a factor of 4.9 g/GJ gross based on 1999 data.

Table 5 Aggregate Emission Factors for Fuel Gas Use.

	CO_2	CH_4	NO_x	CO	NMVOC	SO_2	N_2O	Units
2000	2.60	0.00111	0.00660	0.00637	0.00625	0.000987	0.00021	kg/kg
1999	2.64	0.00127	0.00690	0.00686	0.00784	0.001847	0.00020	kg/kg
1998	2.74	0.00048	0.00670	0.00836	0.00901	0.000326		kg/kg
1997	2.74	0.00063	0.00700	0.00866	0.00968	0.000404		kg/kg
1996	2.66	0.00045	0.00663	0.0087	0.00961	0.000017		kg/kg
1995	2.66	0.00047	0.00712	0.00871	0.00979	0.000088		kg/kg
1990-94	16020	8.05	326	57.9	13.0	3.24	4.9	g/GJ gr

These emissions apply to the mixture of methane, ethane, propane and butane used. In the NAEI database they are reported in the categories:

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

Emissions are reported under 1A1cii Other Energy Industries.

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 CO_2, SO_2, NO_x, CO, NMVOC and methane were taken from the SCOPEC (2001) and UKOOA (1993) studies for 1995-2000 and 1991 respectively. The estimates of the amounts of crude oil and gas burnt are fairly speculative. Data from 1995 were extrapolated to previous years using data on the numbers of wells explored, reported in DTI (2001b). 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 1995-2000 with the 1995 factor used for all previous years. The aggregate emission factors are given in Table 6. Well testing is reported under 1B2a Oil Production since many of the wells produce oil and gas. Emissions of nitrous oxide for the years 1990-1998 were estimated using a factor of 0.00036 kt/well tested based on 1999 data.

Table 6 Aggregate Emission Factors for Well Testing (kt/well explored)

	C^1	SO_2	NO_x	CO	NMVOC	CH_4	N_2O
2000	1.45	0.00002	0.0052	0.026	0.0335	0.0524	0.00014
1999	3.61	0.00006	0.011	0.0558	0.0685	0.151	0.00036
1998	3.73	0.131	0.012	0.0619	0.0656	0.16	
1997	2.78	0.104	0.009	0.0461	0.0519	0.121	
1996	2.34	0.092	0.008	0.0411	0.0462	0.108	
1995	2.69	0.1	0.0087	0.0445	0.0759	0.117	
1990-94	2.69	0.1	0.0087	0.0445	0.0759	0.117	0.00036

1 Emision factor as kt carbon/well

4.4 OTHER EMISSIONS FROM PLATFORMS AND TERMINALS

These include emissions of methane and NMVOC from platforms and terminals arising from cold venting, other fugitive emissions and also from storage of crude oil at terminals. The approach adopted was determined by the data available. For the years 1995-2000, detailed estimates from the SCOPEC (2001) 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 4.1 and 4.2 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 7 Aggregate Emission Factors used for Emissions from Platforms and Terminals

	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

4.5 LOADING EMISSIONS

Emissions from tanker loading and unloading were taken from the SCOPEC (2001) study for 1995-2000. 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) and the Pollution Inventory (Environment Agency, 2001). 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 8 shows aggregate factors calculated from the amounts of oil loaded. Oil shipment data are reported in the CRF tables.

Table 8 Aggregate Emission Factors used for Crude Oil Loading and Unloading (t/kt oil)

	Onshore CH_4	Onshore NMVOC	Offshore CH_4	Offshore NMVOC
2000	0.0118	0.75	0.118	1.66
1999	0.0064	0.69	0.074	1.34
1998	0.013	0.79	0.043	1.44
1997	0.0029	0.78	0.036	1.98
1996	0.0037	0.8	0.035	1.96
1995	0.015	0.77	0.036	2.0
1994	0.014	0.75	0.036	2.0
1993	0.013	0.73	0.036	2.0
1992	0.013	0.72	0.036	2.0
1991	0.015	0.92	0.034	1.91
1990	0.013	0.73	0.036	2.0

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 leakage 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; Williams, 1993). The emissions for 1997-00 are based on the results of a new model (Transco 2000, 2001) 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 methane content of natural gas is shown in Table 9. Following discussions with Transco there have been significant revisions in the composition data used, resulting from clarification of the units used i.e. weight % as opposed to volume %. An extra emission of 40 kt methane is been included to account for high-pressure mains which are not included in the British Gas and Transco models. (DETR, 1999)

Table 9 Methane and NMVOC Composition of Natural Gas

Period	CH_4 weight %	NMVOC weight %
1990-96[1]	84.3	8.9
1997-99[2]	77.1	14.7[3]
2000[3]	77.6	14.7

1 British Gas (1994)
2 Transco (2000)
3 Transco (2001)

4.7 PETROL DISTRIBUTION

The NAEI reports emissions from the storage, distribution and sale of petrol in the following categories each of which is further divided into emissions of leaded and unleaded petrol:

- Refineries (Road/Rail Loading). Emissions during loading of petrol on to road and rail tankers at refineries
- Petrol Terminals (Storage). Emissions from storage tanks at petrol distribution terminals.
- Petrol Terminals (Tanker Loading). Emissions during loading of petrol on to road and rail tankers at petrol terminals.
- Petrol Stations (Petrol Delivery). Emissions during loading of petrol from road tankers into storage tanks at petrol stations.
- Petrol Stations (Storage Tanks). Emissions from storage tanks at petrol stations.
- Petrol Stations (Vehicle Refuelling). Emissions due to displacement of vapour during the refuelling of motor vehicle at petrol stations.
- Petrol Stations (Spillages). Emissions due to spillages during refuelling of motor vehicles at petrol stations.

Emissions would also occur from storage tanks at refineries. This source is included together with emissions from the storage of crude oil and other volatile materials in the NAEI source category, refineries (tankage).

The estimate for road and rail tanker loading at refineries are supplied by UKPIA (2001). The remaining estimates are based on methodologies published by the Institute of Petroleum (2000) or, in the case of petrol terminal storage, based on methods given by CONCAWE (1986). The calculations require information on petrol density, given in DTI (2001), and petrol Reid Vapour Pressure, data for which have been obtained from a series of surveys carried out by the Associated Octel company between 1970 and 1994. The methodology also requires assumptions to be made on the level of vapour recovery in place at terminals and petrol stations. These assumptions have been made taking into account a survey carried out by Petroleum Review (2000) which included questions on petrol station controls, and the timescales recommended in Secretary of State's Guidance for petrol terminals (PG 1/13 (97)). The activity data are the sales of leaded and unleaded petrol taken from DTI (2001).

4.8 REFINERIES AND PETROLEUM 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)

All are based on UKPIA (2001) estimates for 1994-2000. The UKPIA data refer to the following installations:

- Texaco, Milford Haven
- Elf, Milford Haven
- BP, Coryton
- Shell, Shell Haven (closed during 1999)
- Conoco, South Killingholme
- Lindsey, Killingholme
- Shell, Stanlow
- PIP, North Tees
- Esso, Fawley
- BP, Grangemouth
- Gulf, Milford Haven (closed during 1997)

UKPIA also supply estimates for loading of petrol into road and rail tankers at refineries – see section 4.7

Prior to 1994, process emissions are estimated by extrapolation from the 1994 figure on the basis of refinery throughput, whereas emissions from tankage, flares and drainage systems are assumed to be constant.

Also included under 1B2aiv Refining and Storage are NMVOC emissions from the NAEI category petroleum processes. This reports NMVOC emissions from specialist refineries (Llandarcy, Eastham, Dundee, & Harwich), onshore oil production facilities, and miscellaneous petroleum processes not covered elsewhere in the inventory (most significant of which are the Tetney Lock and Tranmere oil terminals). Emissions are taken from the Pollution Inventory, (Environment Agency, 2001). No emissions data have been found for the Dundee refinery.

4.9 GASIFICATION PROCESSES

The NAEI also reports NMVOC emissions from on shore gas production facilities, refining and odourisation of natural gas, natural gas storage facilities, and processes involving reforming of natural gas and other feedstocks to produce carbon monoxide and hydrogen gases. Emissions are taken from the Pollution Inventory (Environment Agency, 2001). 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

CONTENTS

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 (DTI, 2001b). The British Cement Association (2001) advised us that the average CaO content of cement clinker is 63% and the losses of cement kiln dust are around 2%. Also the use of non-carbonate CaO can be assumed zero. Based on these data, a new emission factor of 137.6 t C/kt clinker was calculated according to the IPCC Tier 2 method. This is around 2.5% lower than the emission factor used in the 1999 Inventory which was based on IPCC default values. 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 production 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 cement kilns. Emission factors are shown in Table 1. In DUKES (DTI, 2001), this fuel consumption is included under ‘industry’. Fuel estimates were derived from Blyth *et al* (1996) and British Cement Association (1999, 2000). The BCA data supplied an estimate of total kiln fuel used in 1990, 1995 and 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 (DTI, 2001b), 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, 2001). 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). A further source of uncertainty in these estimates arises from the gross calorific value of petroleum coke. In previous inventories the IPCC default of 32.6 GJ/t gross (31 GJ/t net) was used however for the current inventory, a value of 39.5 GJ/t gross (DTI, 2001) was used. This has a significant effect on the calculation since the petroleum coke data are reported in mass units and the cement fuel consumption as energy units. As a result of this change, the estimated consumption of coal in cement kilns has decreased and that consumed by other industrial sources has increased. Overall, the effect on total carbon emissions will be zero, but there will be small changes in the emissions of other pollutants because different emission factors are used for cement kilns and industrial boilers.

The non-CO_2 factors for scrap tyres are the same as those 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 (2001), the Scottish Environmental Protection Agency (2001) and the DOENI (2001). The aggregate factors were calculated based on estimated plant capacities supplied by British Cement Association (2001). They are expressed in terms of the emission per tonne of clinker produced and are shown in Table 2. Environment Agency data are only available from 1994, and NMVOC data from 1998. Emission factors from later years are used to fill the gaps.

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

	C [a]	CH_4	N_2O	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	14230[d]	0.99[h]	NE	g/GJ gr
Petro-Coke	800[c]	0.42[g]	0.158[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 factor as mass carbon per unit fuel consumed
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	NMVOC	SO_2	Units
1990-94	2.65	4.92	0.0975	2.63	kt/Mt Clinker
1995	2.38	4.28	0.0975	2.73	kt/Mt Clinker
1996	1.95	3.78	0.0975	1.68	kt/Mt Clinker
1997	1.40	4.42	0.0975	1.69	kt/Mt Clinker
1998	2.62	4.13	0.0975	1.98	kt/Mt Clinker
1999	2.53	3.43	0.105	2.44	kt/Mt Clinker
2000	2.62	3.19	0.107	1.83	kt/Mt Clinker

2 Lime Production

Lime (CaO) is manufactured from limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) 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, 2002). 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 sequestrated 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. Emissions of CO, NO_x and SO_2 from limekilns are also estimated from Environment Agency (1998) data extrapolated on limestone consumption. These emissions are fuel combustion emissions and are reported in 1A2f Other Industry. There will be a small double count on these emissions since it has not been possible to correct for limekiln fuel consumption already reported in 1A2f.

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 (2002) and ISSB (2001) 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.

4 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. The pollution inventory reports a significant emission of CO from this process. This arises from the coke consumed in the process and is reported in 1A2f as fuel combustion. The emission is based on the pollution inventory data (Environment Agency, 2001) and is extrapolated to earlier years using plant capacity estimates. There will be a small double count as it has not been possible to correct for the coke consumed.

Some of the uses of the 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, 2001, 2001a). This is around 20% of the mass of glass produced. An emission factor of 113 kt C/ Mt soda ash is used. The estimates include both container, domestic and flat glass and are corrected for the amount of recycled cullet. Hence the soda ash consumption is estimated as 20% of the new glass melted.

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 Fletton Brick Production

Fletton bricks are manufactured in Southern England using the Lower Oxford clay. This clay contains a significant proportion of carbonaceous material, which acts as a fuel during firing, leading to emissions of carbon dioxide, methane, and non-methane volatile organic compounds. Emissions data for recent years are available from the Pollution Inventory (Environment Agency, 2001), but these data will include emissions both from the burning of the carbonaceous material in the clay but also from the burning of coal and gas used as support fuel. Emissions from the carbonaceous material were estimated by estimating the likely emissions from coal and gas combustion in the manufacture of the bricks and then subtracting these estimates from the emissions reported in the Pollution Inventory. The sole company involved in the manufacture of Fletton bricks was approached for supplementary data but did not provide any data. In the absence of these data with which to verify assumptions made, the estimates must be considered very uncertain.

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:

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$
$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

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

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

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

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

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 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 CO_2 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 CO_2 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.

8 Nitric Acid Production

The manufacture of nitric acid produces emissions of both NO_x and nitrous oxide. All plant operators but one were able to supply data on nitrous oxide emissions and production for 2000. The non-reporting plant was estimated using 1999 data. For previous years, emissions were calculated for each plant by extrapolating the earliest reported emission using production or plant capacity data. One plant currently has abatement measures which reduce N_2O emissions 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. In 2000 a further plant closed down. 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. Detailed data were requested from manufacturers according to the IPCC Good Practice Guidance, however the response was incomplete. Much of these data are commercially sensitive and are not reproduced here.

Table 3 Summary of Nitric Acid Production in UK

	1990	1994	1995	1996	1997	1998	1999	2000
No of Sites	8	6	6	6	6	6	6	6[1]
Production/capacity Mt 100% Nitric Acid	2.41	2.43	2.40	2.44	2.35	2.61	2.44	1.92
Aggregate Emission Factor kt N_2O/Mt	5.54	5.71	4.14	4.19	4.12	4.27	6.56	7.65
Aggregate Emission Factor kt NO_x/Mt	3.0	1.93	0.808	0.743	0.902	0.733	0.913	1.06

[1] A plant closed during 2000

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 ranges 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
- installation of an abatement system on a plant in 1999
- plant closures in 2000 and between 1990 and 1994.

The aggregate N_2O emission factor rose between 1998 and 1999. The 2000 Inventory includes measured data on a plant that was recently fitted with abatement measures for NO_x but which had the effect of increasing N_2O emissions. The plant factors used before and after the modification are consistent with the range of values reported in IPCC Good Practice Guidance (2000).

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.

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, 2001). The estimates are based on an emission factor of 0.3 kt N_2O/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 production but prior to 1994 it is included under adipic acid production. This will cause a variation in reported effective emission factor for these years. This allocation reflects the availability of data. In 1998 an N_2O abatement system was retrofitted to the plant. This has resulted in a 91% reduction in emissions in 2000. Emissions, destruction and activity data are reported in the CRF tables attached to this report on a CD ROM.

10 Other Chemical Industry

Emissions of methane from chemical processes are reported under 2B5 Other. On the basis of the IPCC Guidelines for National Greenhouse Gas Inventories, manufacture of the following chemicals were initially investigated with regard to emissions of methane:

- carbon black
- ethylene
- dichloroethylene
- styrene
- methanol

In the case of carbon black, dichloroethylene, and styrene no evidence of any emissions of methane from these processes was found and no estimates have been made. Emissions data for ethylene and methanol processes located in England and Wales are available in the Environment Agency’s Pollution Inventory for recent years. Data for ethylene production processes in Scotland and additional data for some of the processes in England and Wales have been obtained from process operators. In most cases, no data are available for the early part of the time series and, except in cases where the chemical process is known not to have been in existence, the emissions in these years are assumed to be equal to the emissions in the earliest year for which data are available.

Further investigation of data available from the Pollution Inventory showed that other processes, manufacturing different chemicals to those cited in the IPCC Guidelines, were sources of methane. Data for these processes are available for recent years in the Pollution

Inventory, and some further data on emissions in earlier years were obtained from process operators. Where no data are available for the early part of the time series and, except in cases where the chemical process is known not to have been in existence, the emissions in these years are assumed to be equal to the emissions in the earliest year for which data are available. Thus the new inventory reports methane emissions from the following source categories:

- Chemical Industry
- Chemical Industry (methanol)
- Chemical Industry (ethylene)

Here, the first category includes miscellaneous chemical industry processes, not including the manufacture of dichloromethane, styrene, methanol, ethylene, and carbon black.

The new estimates represent an improvement on the 1999 Inventory where a single total based on 1999 data was reported for all years.

Emissions of other pollutants are reported under the following source categories:

- Sulphuric Acid Production - SO_2
- Chemical Industry -CO, SO_2, NMVOC
- Chemical Industry (Carbon Black) - CO, SO_2
- Chemical Industry (Nitric Acid Use) - NO_x
- Chemical Industry (Pigment Manufacture) - SO_2
- Chemical Industry (Reforming) - CO
- Chemical Industry (Sulphuric Acid Use) - SO_2
- Coal, tar and bitumen processes - NMVOC
- Solvent and Oil recovery - NMVOC
- Ship purging - NMVOC

Emissions of NMVOC, reported for the organic chemical industry are based on the Pollution Inventory (Environment Agency, 2001) and data received from the Scottish Environment Protection Agency (SEPA) and process operators in Northern Ireland and Scotland. For the years prior to 1994 for which emissions data are unavailable, estimates for 1994 are extrapolated back using an index of production for the Chemical Industry (ONS, 2001). A revision to the methodology in 1999 is the removal of ship purging emissions from the estimate for NMVOC emissions from the chemical industry, these emissions now being reported as a separate source. The emissions arise from the cleaning of ships tanks used for carrying chemicals, where contamination must be avoided. The estimate is a single figure for all years taken from Rudd *et al* (1996). Two minor sources of NMVOC have been included in the inventory for the first time in 2000: emissions resulting from the processing of coal, tar or bitumen (excluding coke ovens, refining of bitumen, or use of bitumen for road construction), and recovery of solvents or oils from waste chemicals. The emission estimates for these sources are based on the Pollution Inventory (Environment Agency, 2001).

Emissions of sulphur dioxide from sulphuric acid production are based on detailed manufacturers' returns compiled by NSSA (2001). Emissions of SO_2 also occur as a result of the burning of sulphur as part of a single UK process to manufacture pigments, due to the use of sulphuric acid in chemical processes, due to the burning of petroleum fractions to produce carbon black, and due to various other chemical processes which produce SO_2 as a by-product. These emissions are reported in the following categories:

- Chemical Industry (Pigment Manufacture)
- Chemical Industry (Sulphuric Acid Use)
- Chemical Industry (Carbon Black)
- Chemical Industry

The Pollution Inventory provides emissions data for carbon monoxide from carbon black manufacture, processes involving reforming of hydrocarbon feedstocks, and miscellaneous chemical processes which produce carbon monoxide as a by-product. The following three categories are used to report these emissions:

- Chemical Industry (Carbon Black)
- Chemical Industry (Reforming)
- Chemical Industry

Finally, emissions of oxides of nitrogen resulting from use of nitric acid in chemical industry processes are also estimated based on Pollution Inventory data. Emissions are reported in the category Chemical Industry (Nitric Acid Use).

11 Glass production

The use of organic chemicals in binders and coatings used in the production of glass fibres and glass wool can lead to emissions of NMVOC. Data are reported in the Pollution Inventory (Environment Agency, 2001) for recent years and these data are extrapolated back to complete the time series using in-house estimates of glass fibre and glass wool production.

12 Iron and Steel

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

- Iron and Steel Blast Furnaces: CO_2 and other process emissions
- Flaring of blast furnace gas
- Electric Arc Furnaces
- Basic Oxygen Furnaces.
- Rolling Mills (Hot & Cold Rolling)

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 iron and steel processes 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.

12.1 CARBON DIOXIDE EMISSIONS

The methodology used has been revised in light of the IPCC Good Practice Guidance (2000) Tier 2 methodology. This considers a two-stage carbon balance on iron making and steel making.

The UK methodology implements the two-stage approach in the following manner:

Iron Making (Blast Furnaces)

coke + ore → blast furnace gas +pig iron + carbon emission

Steel Making (Basic Oxygen Furnaces)

pig iron +scrap → crude steel +carbon emission

Steel Making (Electric Arc Furnace)

scrap +ore+ graphite anode → steel + carbon emission

Thus for iron making, the mass balance considers the carbon content of the reducing agent (coke) and the carbon content of the ore (zero since carbonate ores are not used in the UK) consumed by the blast furnace. This is balanced by the carbon contained in the pig iron produced and the blast furnace gas produced. In the UK, data are available on the production and consumption of blast furnace gas 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 iron making carbon balance to avoid double counting. Hence, the carbon emission is in effect a residual term reflecting the carbon content of unreported losses of blast furnace gas. In the steel making stage, the carbon balance considers the carbon content of the pig iron consumed in steel making. This is balanced by the carbon sequestrated in the crude steel produced and carbon emitted in the form of BOF gases. In principle, the carbon content of scrap used should be considered, however this is neglected by the IPCC Good Practice Guidance methodology. A large proportion of this is scrap steel recycled internally in the steel industry and so probably does not appear in the steel production statistics, however a proportion will be used scrap bought in from outside the steel industry. As the available data are ambiguous as to the origin of the scrap, and the contribution appears to be small, scrap steel was not considered. In electric arc furnaces, emissions arise from the consumption of the graphite anode and are estimated using a default emission factor as the emission of carbon per tonne of steel produced.

The carbon emission reported under 2C1 Iron and Steel Production can be estimated as:

Emission = A(I&S BF,ck) × e(car,I&S BF,ck)
+A(I&S flaring,bfg) × e(car,s,bfg)
+A(I&S BOF, iron used) × e(car,I&S BOF, iron used)
+A(I&S EAF, steel made) × e(car, I&S EAF, steel made)

- A(bfg produced,bfg) × e(car,s,bfg)
- A(I&S BF, iron made) × e(car,I&S BF, iron made)
- A(I&S BOF, steel made) × e(car,I&S BOF, steel made)

where

A(I&S BF,ck) = Blast furnaces coke consumption (kg)
A(I&S BF, iron made) = Pig iron production (kg)
A(I&S BOF,iron used) = Pig iron used in steelmaking (kg)
A(I&S BOF,steel made) = Crude steel production (kg)
A(I&S EAF,steel made) = Steel production in EAFs (kg)
A(bfg produced, bfg) = Production of blast furnace gas (kJ)
A(I&S flaring, bfg) = Blast furnace gas flared (kJ)
e(car,I&S BF, iron made) = Carbon content of iron made (kg/kg)
e(car,I&S BOF,iron used) = Carbon content of iron used in steel making (kg/kg)
e(car,I&S BOF,steel made) = Carbon content of steel made (kg/kg)
e(car,I&S BF,ck) = Carbon content of coke (kg/kg)
e(car, I&S EAF, steel made) = Carbon emission per kg steel made in electric arc furnaces (kg/kg)
bfg = Blast Furnace Gas
e(car,s,bfg) = Carbon content of blast furnace gas (kg/kJ)

It is assumed that the carbon content of steel is around 1.7 kt C/Mt crude steel (BISPA, 1997) and the carbon content of pig iron around 40 kt C/Mt pig iron (IPCC, 2000). Other carbon contents are 820 kt C/Mt for coke and 59460 g C/GJ for blast furnace gas. Emissions from electric arc furnaces are 3.6 kt C/Mt steel (BISPA, 1997)

The CRF Background Table 2(I).A-Gs2 lists the component sources and sinks together with activity data for the computational scheme above. The sum of the component sources and sinks corresponds to the total carbon emission from 2C1.

12.2 OTHER POLLUTANTS

Emissions from blast furnaces of other pollutants are partly based on the methodology described in IPCC (1997) for blast furnace charging and pig iron tapping. However, a revision has been made to the SO_2 factors based on data supplied by Corus (2001) who use EIPPCB (2000) defaults. The emission factors are expressed in terms of the emission per Mt of pig iron produced and are given in Table 4. Data on iron production are reported in ISSB (2001).

Table 4: Emission Factors for Blast Furnaces, Electric Arc Furnaces and Basic Oxygen Furnaces

	C[a]	CH_4	N_2O	NO_x	SO_2	NMVOC	CO	Units
BF	-40[g]	NE	NE	0.013[f]	0.173[d]	0.012[f]	1.442[f]	kt/Mt pig iron
EAF	3.6[c]	0.01[b]	0.005[b]	0.02[b]	IE	0.09[b]	1.26[h]	kt/Mt Steel
BOF	-1.7[c]	NE	NE	0.012[e]	IE	NE	5.62[d]	kt/Mt Steel

a Emission factor as kt carbon/unit activity
b EMEP/CORINAIR(1999)
c BISPA (1997)
d Corus (2001)

e EIPPCB(2000), Corus (2001, 2000)
f IPCC (1997)
g IPCC(2000)
h Emission factor for 2000 based on Environment Agency (2001)
NE Not Estimated
IE Emission included elsewhere.

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 CO_2 emission arises from the consumption of a graphite anode and is based on manufacturer's data. The emission factors are reported in Table 4.

Emissions from basic oxygen furnaces have been revised based on more detailed data supplied by Corus (2001). The NO_x emission is based on an EIPPCB default and the CO emission is based on plant estimates provided by Corus (2001).

Sinter plant emissions are reported under 1A2a and emission factors are given in Appendix 1.

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 (2001).

There is insufficient activity or emission factor data to make an estimate for emissions from ferroalloys. Emissions of CO_2 will be included in 2C1, since the fuels used as reducing agents are included in the energy statistics.

13 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 5. 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 5 Emission Factors for Aluminium Production

	Units	C [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 Emission factor as kt carbon per unit activity, 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).

14 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, 2001). They arise from primary lead/zinc, secondary copper, secondary lead and various other non-ferrous metal production processes. A time series is estimated by extrapolating using production data reported by the British Geological Survey (2002) in the first three cases, and using an index of production for the non-ferrous metal industries (ONS, 2001) for the remaining source. 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.

15 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 (2001) and data on whiskey production were taken from SWA (2001). 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, 2001).

Table 6: NMVOC Emission Factors for Food and Drink Processing

Food/Drink	Process	Emission Factor	Units
Beer	Barley Malting Wort Boiling Fermentation	0.6[f] 0.0048[f] 0.02[f]	g/L beer
Cider	Fermentation	0.02[f]	g/L cider
Wine	Fermentation	0.2[d]	kg/m^3
Spirits	Fermentation Distillation Casking Spent grain drying Barley Malting Maturation	1.578[d] 0.789[e] 0.395[d] 1.31[d] 4.8[c] 15.78[d]	g/ L alcohol g/ L alcohol g/ L whiskey kg/ t grain kg/ t grain g/ L alcohol
Bread Baking		1[a]	kg/tonne
Meat, Fish & Poultry		0.3[f]	kg/tonne
Sugar		0.0224[b]	kg/tonne
Margarine and solid cooking fat		10[f]	kg/tonne
Cakes, biscuits, breakfast cereal, animal feed		1[f]	kg/tonne
Malt production (exports)		4.8[c]	kg/ t grain
Coffee Roasting		0.55[f]	kg/tonne

a Federation of Bakers (2000)
b Emission factor for 2000 derived from Environment Agency (2001)
c Gibson *et al* (1995)
d Passant *et al* (1993)
e Assumes 0.1% loss of alcohol based on advice from distiller
f EMEP/CORINAIR (1996)

16 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 22production. In the inventory it has been necessary to combine the by-product and fugitive emissions from HCFC 22 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. The emission from the HCFC 22 plant have been revised upwards based on new data on the performance of the recently retrofitted abatement plant.

16.1 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 use of SF_6 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 SF_6 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.

16.2 POTENTIAL EMISSIONS OF HALOCARBONS AND SF_6

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 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 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.

17 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 NAEI estimates emissions from solvent use broken down into a high level of detail. Different methodologies are applied in order to estimate emissions but, in general, one of three approaches is followed:

1. Emissions are estimated as the product of activity statistics and emission factors as used in many other parts of the inventory
2. Emission estimates are made based on data obtained from regulators for each process within the source category
3. Emission estimates are provided by the industry based on returns from member companies – estimates might be provided on a site by site basis, or as a single total for the whole sector.

It is worth noting that the emission factor approach, which is an accurate method for many pollutants and sources, is not always very useful for solvent use. This is partly because it is difficult to generate good emission factors due to the diverse nature of many solvent-using processes. For example, a single print works may use dozens of different inks, each of which might have a different solvent content. Other print works in the same sector will probably use different combinations of inks; thus applying an emission factor calculated from data on ink use at a single plant may introduce significant errors. The other reason why emission factors are not always accurate for solvent-using processes is that many of these processes have been increasingly employing abatement techniques to minimise emissions of VOC, and will continue to introduce more abatement in the coming years. Emission factors, even if accurate for one year, will soon lose their validity. As a result, estimates for many solvent-using processes are now made based on assessment of emissions from each process on a frequently recurring basis. Table 7 summarizes the approach followed for each source.

Table 7 Procedures for Estimation of NMVOC emissions from Solvent Use

Source	Approach	Comments
Aerosols (car care products) Aerosols (cosmetics and toiletries) Aerosols (household products)	Industry data	Estimates provided by the British Aerosol Manufacturers Association
Agrochemicals use	Industry data	Estimates provided by the Crop Protection Association
Coating manufacture (glue) Coating manufacture (ink) Coating manufacture (paint)	Emission factor	Emissions calculated as 2.5% of solvent input to coating manufacturing processes
Decorative paint (retail decorative) Decorative paint (trade decorative) Industrial coatings (agricultural and construction equipment) Industrial coatings (aircraft) Industrial coatings (coil coating) Industrial coatings (commercial vehicles) Industrial coatings (drum coatings) Industrial coatings (high performance) Industrial coatings (marine) Industrial coatings (metal and plastic) Industrial coatings (vehicle refinishing) Industrial coatings (wood) Printing (heatset web offset) Printing (metal decorating) Printing (newspaper) Printing (other flexography) Printing (other offset) Printing (overprint varnishes) Printing (print chemicals) Printing (screen printing)	Industry data / emission factors	The British Coatings Federation has provided activity data, emission factors and emission estimates developed following an extensive consultation exercise with member companies
Dry cleaning	Emission factor	Emissions are estimated by modeling changes in dry cleaning activity and technology relative to 1990, for which year an estimate of solvent use by the sector is available.
Film coating	Data from regulators	Processes within the scope of Secretary of State's Guidance Note PG 6/14
Industrial adhesives Industrial adhesives (pressure sensitive tapes)	Industry data / regulator's data	Solvent consumption estimates are obtained from the Solvent Industry

Source	Approach	Comments
		Association, although data on solvent use and emissions by manufacturers of pressure sensitive tapes are collected from regulators so that the abated solvent can be accounted for.
Industrial coatings (automotive)	Data from regulators	Processes within the scope of Secretary of State's Guidance Note PG 6/20
Industrial coatings (metal packaging)	Industry data / regulator's data	Combination of surveys provided by the Metal Packaging Manufacturers Association and earlier data from regulators
Leather coating	Data from regulators	Processes within the scope of Secretary of State's Guidance Note PG 6/22
Leather degreasing	Industry data	A single estimate of solvent use has been provided by the British Leather Confederation
non-aerosol products (automotive products) non-aerosol products (cosmetics and toiletries) non-aerosol products (domestic adhesives & sealants) non-aerosol products (household products) non-aerosol products (paint thinner/remover)	Emission factors	Emission factors were developed following an in-depth study of the sector in 1994. Emission factors are not expected to change significantly from year to year for this sector.
Other rubber products	Industry data	Estimates of solvent use have been provided by the British Rubber Manufacturers Association
Other solvent use	Industry data	An estimate is calculated from estimates of solvent consumption provided by the Solvent Industry Association
Paper coating	Data from regulators	Processes within the scope of Secretary of State's Guidance Note PG 6/18
Printing (flexible packaging)	Data from regulators	Processes within the scope of Secretary of State's Guidance Note PG 6/17
Printing (publication gravure)	Data from regulators	
Seed oil extraction	Data from	

Source	Approach	Comments
	regulators	
Surface cleaning (1,1,1-trichloroethane) Surface cleaning (dichloromethane) Surface cleaning (hydrocarbons) Surface cleaning (other) Surface cleaning (tetrachloroethylene) Surface cleaning (trichloroethylene)	Industry data / emission factors	Estimates of cleaning solvents have been obtained from a number of industrial sources, and emissions are calculated from these data by applying an emission factor of 1000 kg/tonne for hydrocarbons and 'other' solvents and 900 kg/tonne between 1970 and 1990, decreasing linearly to 800 kg/tonne by 1995 for chlorinated solvents
Textile coating	Data from regulators	Processes within the scope of Secretary of State's Guidance Note PG 6/8
Tyre manufacture	Data from regulators	Data could not be obtained for two plants and so these are assigned an emission equal to the mean emission of the other plants
Wood impregnation (creosote) Wood impregnation (LOSP)	Emission factor	Emissions for light organic solvent based preservative (LOSP) are extrapolated from a single, industry-derived estimate on the basis of the output of the UK wood products industry.

In the case of estimates based on data from regulators, it should be noted that solvent-using processes in Northern Ireland were not regulated in the same way as those in the rest of the UK at the times that data were obtained, and thus no data are available for plants in Northern Ireland. However, with the exceptions of tyre manufacture, and probably flexible packaging printworks and textile coating processes, it is not thought that any processes of these types are in operation in the region.

An estimate is included of the carbon dioxide equivalent of the solvent consumption. This estimate is based on applying speciation data (Passant, 2002) to the solvent emissions and calculating their total carbon content. A factor of 0.664 kg C/kg CO_2 was estimated based on 1999 data and applied to all years. The CO_2 estimate is included as a footnote to IPCC Table 3 and is not included in the National Total.

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