In addition, wood stoves (where there is a great variation in technology by geographic region) may have particularly high emissions rates of NMVOC due to their largely inefficient combustion of fuel.

The NMVOC emissions from mobile sources are a function of the amount of hydrocarbons passing unburnt through the engine. This depends on engine type, fuel used, use of post-combustion emission controls (e.g., catalytic converters) and driving regime. The emissions are generally highest at low speeds and when the engine is idle. Poorly tuned engines may have a particularly high output of hydrocarbon compounds.

NMVOC evaporative emissions from gasoline mobile sources should be accounted for here.

The general method for estimating NMVOC can be described as:

$$\text{Emissions} = \sum (EF_{ab} \times \text{Activity}_{ab})$$

where:

EF = Emission Factor (kg/TJ);
Activity = Energy Input (TJ);
a = Fuel type; and
b = Sector-activity.

Due to large differences in emission factors for various sectors, fuel consumption must be allocated to the IPCC main activity groups.

Extensive NMVOC emission factor data are available for most of the fuel combustion sources. The following default emission factors have been developed by the IPCC based on the CORINAIR90 database, Radian (1990), US EPA (1995), the EDGAR Version 2.0 database, and National Communications to the FCCC. The aggregated emission factors in this table allow a rough estimation of NMVOC emissions.

TABLE 1-11
NMVOC DEFAULT (UNCONTROLLED) EMISSION FACTORS (IN KG/TJ)

			Coal	Natural Gas	Oil	Wood/ Wood Waste	Charcoal	Other Biomass and Wastes[a]
Energy Industries			5	5	5	50[b]	100[b]	50
Manufacturing Industries and Construction			20	5	5	50	100	50
Transport	Aviation[c]				50			
	Road			5	Gasoline: 1500[d]; Diesel: 200			
	Railways		20		200			
	Navigation		20		200			
Other Sectors	Commercial/Institutional		200	5	5	600	100	600
	Residential		200	5	5	600	100	600
	Agriculture/ Forestry/ Fishing	Stationary	200	5	5	600	100	600
		Mobile		5	200			

Note: These factors are considered as the best available global default factors to date.

(a) Includes dung and agricultural, municipal and industrial wastes.

(b) These factors are for fuel combustion in the energy industries. For charcoal production, please refer to Table 1-14, Default Non-CO_2 Emission Factors for Charcoal Production.

(c) The emission factor for aviation in the above table is for jet kerosene. The emission factor for aviation gasoline is 300 kg/TJ.

(d) These factors are the sum of combustion and evaporative emissions from gasoline use. The NMVOC emission factors for mobile sources from evaporation of gasoline vary with the ambient temperature. In general, in the "warmer" countries the emission factors will be higher than in "colder" countries.

1.4.2.6 SULPHUR DIOXIDE (SO_2) EMISSIONS FROM FUEL COMBUSTION

Sulphur dioxide is not a "greenhouse gas" but its presence in the atmosphere *may* influence climate. SO_2 can react with a variety of photochemically produced oxidants to form sulphate aerosols. The concentration of these particles is increasing due to the burning of fossil fuels which contain sulphur. Over limited regions of the northern hemisphere, the effect of these particles is comparable in size, although opposite in effect, to that of human generated greenhouse gases up to the present time. Any effect of sulphur dioxide emissions on climate change can be expected to be strongly regional in character - but studies of this with climate models need to be carried out (Houghton, 1994). Although SO_2 is not a direct greenhouse gas, it is an aerosol precursor and as such, has a cooling effect on climate.

Anthropogenic SO_2 emissions world-wide amount to 70-80 million tonnes per year (Mt/y) (Vernon and Jones, 1993). This compares with natural emissions of 18-70 Mt/y (IPCC, 1992). There is, however, a paucity of information on the relative contribution of sulphur emissions arising from combustion, due to lack of detailed information on the sulphur level of the fuel consumed. More than 80 per cent of anthropogenic SO_2 arises from fuel combustion, with three-quarters of this arising from coal (Vernon, 1990). At present an estimated 10 Mt/y of coal-related SO_2 emissions are removed by flue-gas desulphurisation technology world-wide (Ando, 1992).

The general method for estimating SO_2 can be described as:

$$\text{Emissions} = \sum (EF_{ab} \times Activity_{ab})$$

where:

EF = Emission Factor (kg/TJ);
Activity = Energy Input (TJ);
a = Fuel type; and
b = Sector-activity.

The emissions of sulphur oxides (SO_x) are directly related to the sulphur content of the fuel, which for coal can vary from below 0.5 to over 10 per cent by weight. The majority of coals currently in use are in the range 0.5 to 3 per cent. Generally the "southern hemisphere" coals contain less sulphur than "northern hemisphere" coals.

For fuel oil (including heavy fuel oil) sulphur content varies from 0.3 to over 5 per cent. Lighter products may contain minimal sulphur (<0.3 per cent), whilst heavy fuel oil can contain from up to 3-5 per cent sulphur. Currently the world average sulphur content of crude oil is around 1.3 per cent, although there are considerable variations between different sources (Vernon and Jones, 1993).

The sulphur content of gas is usually negligible.

The SO_2[13] emission factors can be estimated as:

$$EF_{SO_2}\ [kg/TJ] = 2 \times \left(\frac{s}{100} \right) \times \frac{1}{Q} \times 10^6 \times \left(\frac{100 - r}{100} \right) \times \left(\frac{100 - n}{100} \right)$$

where:

EF = Emission Factor (kg/TJ);
2 = SO_2/S [kg/kg];
s = Sulphur content in fuel [%];
r = Retention of sulphur in ash [%];
Q = Net calorific value [TJ/kt];
10^6 = (Unit) conversion factor; and
n = Efficiency of abatement technology and/or reduction efficiency [%].

Sulphur appears in coal as pyritic sulphur (FeS_2), organic sulphur, sulphur salts and elemental sulphur. Pyritic and organic sulphur account for the vast majority of sulphur in coal and both types are responsible for SO_x formation. The sulphur is released when the coal is burnt, mainly oxidised to SO_2. Usually less than 1-2 per cent of the total sulphur is released as SO_3.

[13] Sulphur dioxide (SO_2 + SO_3 expressed as SO_2 mass equivalent).

TABLE 1-12 SAMPLE AND DEFAULT VALUES OF SULPHUR CONTENT (S) IN FUEL			
Fuel (IPCC grouping)		**Default value[a] [%]**	**CORINAIR 90[b] range [%]**
Coal	- low S	0.5	≥ 0.001
	- medium S	1.5	-
	- high S	3.0	≤ 16.1
Heavy fuel oil	- low S	1.0	≥ 0.001
	- medium S	3.0[c]	-
	- high S	4.0	≤ 4.0
Light fuel oil/diesel	- low S	0.3	≥ 0.14
	- high S	1.0	≤ 1.0
Diesel (road)		0.3	0.1-1.0
Gasoline (road)		0.1	0.012 - 0.15
Jet kerosene		0.05	0.0001-0.3[d]
Oil shale		1.5(1.3-1.7)[e]	NAV
Natural gas		negligible	NAV
Municipal waste		0.003	0.003
Industrial waste		0.2	0.200 - 1.000
Black liquor		1.5	0.004 - 8.09
Fuelwood		0.2	0.001-0.06
Other biomass		< 0.03	0.001 - 0.800

(a) To be used only if no better information is available.

(b) Fuels used in CORINAIR 90 inventories in the Czech Republic, Denmark, France, Hungary, Italy, the Netherlands, Poland and the Slovak Republic.

(c) The medium value refers to the default for marine bunkers.

(d) Values reported in literature.

(e) Values from Estonia.

During fuel combustion, part of the sulphur is retained in ash. The sulphur retention in ash for coal ranges from 5 to 60 per cent, (usually less than 10 per cent). The proportion depends upon the composition of the ash. The sulphur retention in ash for liquid fuels and biomass is minimal and can be disregarded.

Default Values for the Sulphur Retention (r) in Ash [%]	
Hard coal	5
Brown coal	30

If abatement technologies for SO_x emissions reduction are used, the estimated emission factors for SO_2 should be correspondingly reduced. Reduction efficiency values for different types of abatement technologies may vary between 45 and 95 per cent (Rentz, et al., 1992).

1.4.3 Biomass Data

The tables below provide data for use within the Reference Approach or for the calculation of all emissions by source categories using the methods described in Sections 1.4.1 and 1.4.2.

TABLE 1-13
ENERGY CONTENT OF BIOMASS FUELS: DEFAULT NET CALORIFIC VALUES

Biomass Fuel	Moisture Content (% mcwb)(a)	Typical Net Calorific Value(b) (MJ/kg)	Reference
BASIC BIOFUEL TYPES:			
Fuelwood(c)	20	15	Hall et al. (1994b)
Charcoal		30	Hall and Mao (1994a)
Dung		12	GOB (1987)
Bagasse	50	8	Leach and Gowen (1987)
Agricultural Waste		15	Leach and Gowen (1987)
Other Waste		11	US EPA (1995)
EXAMPLES OF SPECIFIC BIOFUELS:			
Wood			
Wet, freshly cut	40	10.9	Leach and Gowen (1987)
Air-dry, humid zone	20	15.5	Leach and Gowen (1987)
Air-dry, dry zone	15	16.6	Leach and Gowen (1987)
Oven-dry	0	20.0	Leach and Gowen (1987)
Charcoal	5	29.0	Leach and Gowen (1987)
Bagasse			
Wet	50	8.2	Leach and Gowen (1987)
Air-dry	13	16.2	Leach and Gowen (1987)
Dung cakes (dried)	12	12.0	Leach and Gowen (1987)
OTHER AGRICULTURAL RESIDUES:			
Coffee Husks	12	16.0	Leach and Gowen (1987)
Ricehulls (air-dry)	9	14.4	Leach and Gowen (1987)
Wheat straw	12	15.2	Leach and Gowen (1987)
Maize (stalk)	12	14.7	Leach and Gowen (1987)
Maize (cobs)	11	15.4	Leach and Gowen (1987)
Cotton gin trash	24	11.9	Leach and Gowen (1987)
Cotton stalk	12	16.4	Leach and Gowen (1987)
Coconut husks	40	9.8	Leach and Gowen (1987)
Coconut shells	13	17.9	Leach and Gowen (1987)

(a) mcwb : moisture content weight basis.
(b) Typical values to be considered as rough approximations.
(c) Assuming air dry wood.

Values for estimating the amount of carbon released through charcoal production and consumption, the wood-to-charcoal factor, are stated to be between 4 and 8. If no local information is available, 6 kg of wood input per kg of charcoal may be used as default

(FAO, 1990). In many developing countries, there are usually no cross checks on the quality of charcoal. Consequently, substandard charcoal will be passed on as charcoal. Typical wood to charcoal conversion factors in many developing countries would range from 2.5 to 3.5 and rarely beyond this. This also implies that the carbon fraction of charcoal is around 0.6 to 0.7. Default emission factors related to the production of charcoal are presented in the Table I-14

TABLE I-14
DEFAULT NON-CO_2 EMISSION FACTORS FOR CHARCOAL PRODUCTION (IN KG/TJ)

Compound	Default Emission Factor (kg/TJ of Wood Input)(a)	Default Emission Factor (kg/TJ of Charcoal Produced)
CH_4	300	1000
N_2O	NAV	NAV
NO_x	5	10
CO	2000	7000
NMVOC	600	1700
SO_2	NAV	NAV

(a) Assuming 1 kg charcoal is produced from 6 kg wood and the energy content for wood and charcoal is 15 and 30 MJ/kg respectively, 1 TJ charcoal produced is equivalent to 3 TJ wood input.

1.5 Detailed Methods (Tiers 2 and 3) for Fuel Combustion

1.5.1 Overview

Identification and quantification of greenhouse gas emissions by source category and economic sector, together with a sound understanding of plant combustion conditions, are essential for the study of abatement procedures and the formulation of abatement policy options. Equally, assessment of the effects of emissions on the atmosphere and climate requires detailed data on the magnitude and spatial distribution of pollutant emissions. Both sets of requirements are served by the estimation of emissions from combustion activities categorised by plant types at a level of detail for which an emission factor can be reasonably narrowly specified. Studies of the products of combustion from many types of plant under different operating conditions have resulted in a growing database of emission factors linking the emission rate to the activity. Estimation methodologies using these emission factors are described and discussed in this section.

In what follows, the emission sources are grouped into stationary and mobile sources and representative emission factors for them are assembled for use in a simple formula common to the majority of cases. The distinction between Tier 1 methods and those of Tiers 2 and 3 rests mainly on the reliance of the first on widely available fuel supply data which, by its nature, takes no account of the combustion technology to which the fuel is delivered. Distinguishing between Tiers 2 and 3 is less easily done as there is a steadily increasing degree of refinement and detail in the emissions estimation process as the methods are developed from one tier to another. However, Tier 2 methods may be regarded as those dividing fuel consumption on the basis of sample or engineering knowledge between technology types which are sufficiently homogenous to permit the use of representative emission factors. Tier 3 methods generally estimate emissions from activity figures (kilometre travelled or tonne-kilometre carried, not fuel consumption) and specific fuel efficiency or fuel rates or, alternatively, using an emission factor or factors expressed directly in terms of a unit of activity.

A new methodology, developed from that used by CORINAIR, has been introduced for the estimation of emissions from aircraft. Revised emission factors are also given for emissions from many types of stationary combustion and road transport in the United States and Europe.

Estimating CO_2

It follows from the arguments given above for the construction of detailed emission estimates that a country will also benefit from the estimation of CO_2 emissions in parallel with the calculation of non-CO_2 inventories despite the existence of Tier 1 methods for CO_2 estimation. The *Overview* to this Chapter also emphasises this point. Most of the tables of emission factors for mobile sources, but few of the tables for stationary sources, have figures for CO_2. In cases where CO_2 emission factors are not given the carbon emission factors provided for the fuel types listed for the Tier 1 methods will suffice. If different fuel qualities are used in different applications national experts may wish to vary the emission factors accordingly.

Where CO_2 emission factors are given in this Chapter they include all carbon based molecule emissions from the process. This ensures that CO_2 totals constructed by summing the results of the detailed estimation of emissions (the "bottom-up" approach) will be comparable with the IPCC Reference Approach described under Tier 1 methods above. The Reference Approach provides a simple transparent and verifiable means of accounting for all of the carbon in fuels which could be emitted to the atmosphere. Because of the complexity of covering all sources of fuel combustion and obtaining the related data it does not automatically follow that summing emissions from the many detailed sources will result in a figure close to that obtained from the Reference Approach. Consequently, verification of CO_2 totals against the Reference Approach is an obligation of the IPCC reporting system.

Use of carbon emission factors based on the fuel's carbon content also implies that adjustments may be needed (depending on the combustion process under consideration) for any carbon unoxidised. Carbon remaining unoxidised after combustion is discussed in Section 1.4.1.1. Where emission estimates are prepared by plant type the general information given in the section cited may be used when more specific carbon unoxidised factors are not available. At the level of process detail implicit in Tiers 2 and 3, quantities of fuel combusted should be known or fairly well estimated and quantities delivered for the manufacture of non-energy products identified and excluded. Where this is not the case estimates of carbon stored in manufactured products will need to be made in collaboration with national experts preparing estimates of emissions from Industrial Processes to ensure that there is no double counting of emissions.

DATA SOURCES

National experts working on detailed emission of non-CO_2 GHGs (particularly the indirect gases) and SO_2 should consult the extensive literature on emission factors and other estimation procedures which has been developed by other inventory programmes outside of the framework of the IPCC/OECD/IEA programme. These data generally contain more technology detail, and are further broken down by size of the various technologies. For mobile sources, data generally contain more vehicle and control technology detail, and are further broken down by operating conditions (e.g., catalyst vintages, driving cycles). The nature of these control assumptions should be known and carefully matched with actual conditions in the country when selecting the specific factors to be used.

Some key examples of data sources are:

- Default Emission Factors Handbook (European Environment Agency Task Force, Bouscaren, 1992)
- CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic, Volume 1: Methodology and Emission Factors (Eggleston, et al., 1992)
- CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic, Volume 2: COPERT Model, Users Manual (Andrias, et al., 1992)
- Atmospheric Emission Inventory Guidebook (Joint EMEP/CORINAIR, European Environment Agency, 1996)
- US EPA's Compilation of Air Pollutant Emissions Factors (AP-42), 4th Edition 1985, (US EPA, 1985a and 1985b), 5th Edition 1995 (US EPA, 1995) and Supplement F, (US EPA, 1993b)

- US EPA's MOBILE5a (US EPA 1994a). Contact Terry Newell, US EPA Office of Mobile Sources, 2565 Plymouth Road, Ann Arbor MI 48105, USA; tel: (313) 668-4462, Email: Newell.Terry@epamail.epa.gov or access the latest information on mobile sources on the world wide web at http://www.epa.gov/OMSWWW/omshome.htm.
- Criteria Pollutant Emission Factors for the 1985 NAPAP Emissions Inventory (Stockton and Stelling, 1987)
- Proceedings of the TNO/EURASAP Workshop (TNO, 1993)
- EMEP and CORINAIR Emission Factors and Species Profiles for Organic Compounds. (Veldt, 1991)
- Transport Statistics for Europe (UN ECE, 1989)
- World Road Statistics (International Road Federation, 1990)
- Other compilations of emission factors include

- Netherlands	Bakkum, et al., 1987, Okken, 1989
- Norway	Statens forurensningstilsyn, 1990
- Germany	Brieda and Pakleppa, 1989, Fritsche, 1989, Rentz et al., 1988, Walbeck, et al., 1988
- Japan	JAERI, 1988
- United Kingdom	Eggleston and McInnes, 1987
- UNEP Country Studies	
- US Country Studies, US CSP, 1996	
- National Communications to the FCCC	

1.5.2 Stationary Combustion

1.5.2.1 OVERVIEW

This section considers emissions of NO_x, N_2O, CO, CH_4, SO_2 and NMVOCs from stationary combustion plant. Estimation of CO_2 emissions at the level of detail of Tiers 2 and 3 is described in Section 1.5.1.

The section focuses on emissions from the combustion of commercial fuels, which include virtually all fossil fuels and biomass fuels *traded commercially* and used in large combustion plants. Non-CO_2 emissions from combustion of biomass are estimated in exactly the same manner as fossil fuel combustion emissions.[14].

Emissions of non-CO_2 greenhouse gases across activities (sectors and subsectors) will depend upon fuel, technology type and pollution control policies. Emissions will also vary with the size and vintage of the combustion technology, its maintenance, and its operation. Most of a country's NO_x emissions arise from stationary fuel combustion. As defined here (i.e., excluding "traditional" small scale use of biomass), this category generally contributes a smaller but still significant share of national emissions of CO and NMVOC, and, to a lesser extent, of N_2O and CH_4. These two gases are nonetheless discussed in some detail because of their priority status within the IPCC/OECD/IEA programme.

[14] See Section 1.4.3 for a discussion of CO_2 emissions from biomass combustion.

A section on SO_2 has been added to the Tier 1 methodology. In the more detailed Tier 2 approach the same basic formula should be applied to more detailed fuel information.

1.5.2.2 RECOMMENDED METHODOLOGY

General Method

Estimation of emissions from stationary sources can be described using the following basic formula:

$$\text{Emissions} = \sum (EF_{abc} \times \text{Activity}_{abc})$$

where:

EF = Emission Factor (kg/TJ);

Activity = Energy Input (TJ);

a = Fuel type;

b = Sector-activity; and

c = Technology type.

Total emission for a particular country is the sum across activities, technologies and fuels of the individual estimates.

Emission estimation is based on at least three distinct sets of assumptions or data: 1) emission factors; 2) energy activities; and 3) relative share of technologies in each of the main energy activities. Sources of the emission factors and energy activity data that are relevant internationally are described briefly below and suggestions on appropriate use of such data are made.

Technology share or technology splits for each of the various energy activities are needed at least on a national level for non-CO_2 greenhouse gas estimation since emission levels are affected by the technology type. Unfortunately, there is no complete international source of data on technology splits and, as a result, each country will need to develop its own technology splits for each energy activity.

The main steps in the inventory method can be summarised as follows:

1 Determine the source and form of the best available, internationally verifiable, national (or sub-national) energy activity data.

2 Based on a survey of national energy activities, determine the main categories of emission factors.

3 Compile best available emission factor data for the country, preferably from national sources. If no national sources are available, select from the options described here. Selection among the options should be based on the similarity of the country to the source of original measurements for types of technology and operating conditions across main energy activities. The selection should also consider the extent to which control technologies may be in place and requires the ability to clearly separate and understand control policy assumptions that may be embedded in the emission factor data.

4 Based on the form of the selected emission factors, identify the technology categories to be used in the national inventory.[15]

5 Using these assumptions on technology categories, develop estimates for each of the greenhouse gases for each main activity.

6 Sum the individual activity estimates to arrive at the national inventory total for each of the greenhouse gases.

Technology Splits for Energy Data

National data or assumptions on the technology shares of each of the main source sector categories which have been identified as important in each country are necessary to create the linkage between national energy balances and the emission factors. Again, this may be based on "bottom-up" data collection at as detailed a level as individual sources, or it may be more of a “top-down” allocation based on statistical sampling, or engineering judgement. The objective is to match up fuel use, by fuel type, with specific technologies or classes of technologies, for which credible emission factors for non-CO_2 gases can be provided.

Emission Factor Data

Emission factors for all non-CO_2 greenhouse gases from combustion activities vary to lesser or greater degrees with:

- fuel type
- technology
- operating conditions
- maintenance and vintage of technology

and so represent the average emission performance of similar technologies.

They are therefore technology specific, but may still represent a wide distribution of possible values because of the influence of the other three factors above. When available, the standard deviation of the emission factor should be used to show the range of possible emission factors, and hence emissions, for each particular energy activity.[16]

1.5.2.3 EMISSION FACTORS

Some tables of representative emission factors for NO_x,[17] CO, CH_4, N_2O and NMVOCs by main technology and fuel types (based on Radian, 1990) were presented in the preliminary methodology manual (OECD, 1991) distributed by the IPCC. This information is still useful in showing the range and variation of sources and emission rates, and it is

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[15] This may also require assumptions about the control technologies in place.

[16] Unfortunately, the standard deviation of emission factors is rarely reported with emission factor data. One study shows that when considered, variation of emission factors within an energy activity vary widely, from 20 to more than 50 per cent (Eggleston and McInnes, 1987).

[17] The convention in this document is that NO_x emissions from fossil fuel combustion are expressed on a full molecular basis assuming that all NO_x emissions are emitted as NO_2.

reproduced in Tables 1-15 to 1-19 for the major categories.[18] All factors are expressed on a kilograms per terajoule of energy input basis (unless stated otherwise) and are stated on a full molecular weight basis. These data are taken from Radian (1990) and show uncontrolled emission factors for each of the technologies indicated. These emission factor data therefore do not include the level of control technology that might be in place in some countries. For instance, for use in countries where control policies have significantly influenced the emission profile, either the individual factors or the final estimate will need to be adjusted.

It may be necessary to make adjustments to "raw" emission estimates to account for control technologies in place. Alternative control technologies, with representative percentage reductions, are shown in Tables 1-20 to 1-23 (Radian, 1990) for the main control technologies applicable to each sector. These tables reflect technologies in use for large stationary sources in OECD countries. Preliminary indications are that, in the rest of the world, control technologies are not typically used (see OECD/IEA, 1991). These data should be used in combination with the uncontrolled emission factors to develop a "net" representative emission factor for each of the technologies to be characterised in the national emission profile; alternatively, the emission estimate for each technology could be adjusted downward according to the indicated percentage reduction and the estimated penetration of the control technology.

Table 1-24 provides the fuel property assumptions upon which the Radian data are based.

The emission factor data in these tables are provided primarily for illustrative purposes. These factors could be used as a starting point or for comparison by national experts working on detailed "bottom-up" inventories. More detail on current emission factors and references is presented in the section on Data Sources.

No emission factors for SO_2 are presented in Tables 1-15 to 1-19. These emission factors should be estimated based on the sulphur content of the fuels (see Section 1.4.2.6, Sulphur Dioxide Emissions from Fuel Combustion).

In many countries, biomass is used in traditional, small-scale facilities and open stoves. Emission factors presented in Tables I-16, 1-18 and 1-19 are for industrial combustion and large-scale facilities.

[18] Note: several printing errors occurred in the 1995 *Guidelines*. These have been corrected here.

TABLE 1-15
UTILITY BOILER SOURCE PERFORMANCE

Basic Technology	Configuration	Emission Factors (kg/TJ energy input)				
		CO	CH_4	NO_x	N_2O	NMVOCs
Coal						
Pulverised Bituminous Combustion	Dry Bottom, wall fired	9	0.7	380	1.6	NAV
	Dry Bottom, tangentially fired	9	0.7	250	0.5	NAV
	Wet Bottom	9	0.9	590	1.6	NAV
Bituminous Spreader Stokers	With and without re-injection	87	1.0	240	1.6	NAV
Bituminous Fluidised Bed Combustor	Circulating Bed	310	1.0	68	96	NAV
	Bubbling Bed	310	1.0	270	96	NAV
Bituminous Cyclone Furnace		9	0.2	590	1.6	NAV
Anthracite Stokers		10	NAV	160	NAV	NAV
Anthracite Fluidised Bed Combustors		5.2	NAV	31	NAV	NAV
Anthracite Pulverised Coal Boilers		310	NAV	NAV	NAV	NAV
Pulverised Lignite Combustion	Dry Bottom, tangentially fired	NAV	NAV	130	NAV	NAV
	Dry Bottom, wall fired	45	NAV	200	NAV	NAV
Lignite Cyclone Furnace		NAV	NAV	220	NAV	NAV
Lignite Spreader Stokers		NAV	NAV	100	NAV	NAV
Lignite Atmospheric Fluidised Bed		2.8	NAV	63	42	NAV
Oil						
Residual Fuel Oil/Shale Oil	Normal Firing	15	0.9	200	0.3	NAV
	Tangential Firing	15	0.9	130	0.3	NAV
Distillate Fuel Oil	Normal Firing	16	0.9	220	0.4	NAV
	Tangential Firing	16	0.9	140	0.4	NAV
Distillate Fuel Gaseous Turbines		21	NAV	300	NAV	NAV
Large Diesel Fuel Engines >600hp (447kW)		350	4.0	1300	NAV	NAV
Natural Gas						
Boilers		18	0.1(a)	250	NAV	NAV
Large Gas-Fired Gas Turbines >3MW		46	6*	190	NAV	NAV
Large Dual-Fuel Engines		340	240	1300	NAV	NAV
Municipal Solid Waste (MSW)						
Mass Burn Waterwall Combustors		22	NAV	170	NAV	NAV
MSW - Mass Feed(a)		98	NAV	140	NAV	NAV

Source: US EPA (1995).
(a) Adapted from Radian, 1990.

TABLE 1-16
INDUSTRIAL BOILER PERFORMANCE

		Emission Factors (kg/TJ energy input)				
Basic Technology	**Configuration**	**CO**	**CH_4**	**NO_x**	**N_2O**	**NMVOCs**
Coal						
Bit./Sub-bit. Overfeed Stoker Boilers		110	1.0	130	1.6	NAV
Bit./Sub-bit. Underfeed Stoker Boilers		190	14	170	1.6	NAV
Bit./Sub-bit. Hand-fed Units		4800	87	160	1.6	NAV
Bituminous/Sub-bituminous Pulverised	Dry Bottom, wall fired	9	0.7	380	1.6	NAV
	Dry Bottom, tangentially fired	9	0.7	250	0.5	NAV
	Wet Bottom	9	0.9	590	1.6	NAV
Bituminous Spreader Stokers		87	1.0	240	1.6	NAV
Bit./Sub-bit. Fluidised Bed Combustor	Circulating Bed	310	1.0	68	96	NAV
	Bubbling Bed	310	1.0	270	96	NAV
Anthracite Stokers		10	NAV	160	NAV	NAV
Anthr. Fluidised Bed Combustor Boilers		5.2	NAV	31	NAV	NAV
Anthracite Pulverised Coal Boilers		NAV	NAV	310	NAV	NAV
Oil						
Residual Fuel Oil Boilers		15	3.0	170	0.3	NAV
Distillate Fuel Oil Boilers		16	0.2	65	0.4	NAV
Small Waste Oil Boilers <0.1MW		15	NAV	58	NAV	NAV
LPG Boilers	Propane	17	NAV	96	NAV	NAV
	Butane	16	NAV	97	NAV	NAV
Small Stationary Internal Comb. Engines	Gasoline <250hp (186 kW)	27	NAV	0.7	NAV	NAV
	Diesel <600hp (447 kW)	0.4	NAV	1.9	NAV	NAV
Large Stationary Diesel Engines >600hp (447 kW)		0.3	0.0	1.3	NAV	NAV
Natural Gas						
Large Boilers >100 MBtu/h (293 MW)		18	1.4	250	NAV	NAV
Small Boilers 10-100 MBtu/h (29.3-293 MW)		16	1.4	64	NAV	NAV
Heavy Duty Nat. Gas Compressor Eng.	Turbines	2.0	0.6	4.1	NAV	NAV
	2-Cycle Lean Burn	4.7	17	33	NAV	NAV
	4-Cycle Lean Burn	5.1	13	39	NAV	NAV
	4-Cycle Rich Burn	20	2.9	28	NAV	NAV
Wood						
Fuel Cell/Dutch Oven Boilers		290	NAV	17	NAV	NAV
Stoker Boilers		590	15	65	NAV	NAV
FBC Boilers		61	NAV	87	NAV	NAV
Bagasse/Ag. Waste Boilers		NAV	NAV	68	NAV	NAV
MSW						
MSW Boilers	Mass Burn Waterwall	22	NAV	170	NAV	NAV
	Mass Burn Rotary Waterwall	36	NAV	110	NAV	NAV
	Mass Burn Rotary Refrac. Wall	64	NAV	120	NAV	NAV
	Modular, Excess Air	NAV	NAV	120	NAV	NAV
	Modular, Starved Air	14	NAV	150	NAV	NAV
Refuse Derived Combustors		90	NAV	240	NAV	NAV

Source: US EPA (1995).

TABLE 1-17
KILNS, OVENS, AND DRYERS SOURCE PERFORMANCE

		Emission Factors (kg/TJ energy input)[a]				
Industry	**Source**	**CO**	**CH_4**	**NO_x**	**N_2O**	**NMVOCs**
Cement, Lime	Kilns - Natural Gas	83	1.1	1,111	NAV	NAV
Cement, Lime	Kilns - Oil	79	1.0	527	NAV	NAV
Cement, Lime	Kilns - Coal	79	1.0	527	NAV	NAV
Coking, Steel	Coke Oven	211	1	35[b]	NAV	16[b]
Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer - Natural Gas	11	1.1	64	NAV	NAV
Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer - Oil	16	1.0	168	NAV	NAV
Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer - Coal	179	1.0	226	NAV	NAV

Source: Radian, 1990.

(a) Values were originally based on gross calorific value; they were converted to net calorific value by assuming that net calorific values were 5 per cent lower than gross calorific values for coal and oil, and 10 per cent lower for natural gas. These percentage adjustments are the OECD/IEA assumption on how to convert from gross to net calorific values.

(b) Joint EMEP/CORINAIR (1996).

TABLE 1-18
RESIDENTIAL SOURCE PERFORMANCE

		Emission Factors (kg/TJ energy input)				
Basic Technology	**Configuration**	**CO**	**CH_4**	**NO_x**	**N_2O**	**NMVOCs**
Coal						
Anthracite Space Heaters		NAV	150	55	NAV	NAV
Coal Hot Water Heaters[a]		18	NAV	160	NAV	NAV
Coal Furnaces[a]		480	NAV	230	NAV	NAV
Coal Stoves[a]		3600	NAV	180	NAV	NAV
Oil						
Residual Fuel Oil		15	1.4	170	NAV	NAV
Distillate Fuel Oil		16	0.7	65	NAV	NAV
Furnaces		16	5.8	59	0.2	NAV
Propane/Butane Furnaces[a]		10	1.1	47	NAV	NAV
Natural Gas						
Furnaces		18	NAV	43	NAV	NAV
Gas Heaters[a]		10	1	47	NAV	NAV
Wood						
Wood Pits[a]		4900	200	150	NAV	NAV
Fireplaces		11000	NAV	110	NAV	NAV
Stoves	Conventional	10000	210	120	NAV	NAV
	Non-catalytic	6100	NAV	NAV	NAV	NAV
	Catalytic	4500	380	87	NAV	NAV
	Pellet, Certified	1700	NAV	600	NAV	NAV
	Pellet, Exempt	2300	NAV	NAV	NAV	NAV
Masonry Heater	Exempt	6500	NAV	NAV	NAV	NAV

Source: US EPA (1995).

(a) Adapted from Radian, 1990.

TABLE 1-19
COMMERCIAL SOURCE PERFORMANCE

		Emission Factors (kg/TJ energy input)				
Basic Technology	**Configuration**	**CO**	**CH_4**	**NO_x**	**N_2O**	**NMVOCs**
Coal						
Coal Boilers[a]		200	10	240	NAV	NAV
Oil						
Residual Fuel Oil/Shale Oil		15	1.4	170	0.3	NAV
Distillate Fuel Oil		16	0.7	65	0.4	NAV
Waste Oil Space Heaters	Vaporising Burner	5.0	NAV	33	NAV	NAV
	Atomising Burner	6.3	NAV	48	NAV	NAV
LPG Boilers	Propane	8.4	NAV	71	NAV	NAV
	Butane	12	NAV	70	NAV	NAV
Natural Gas						
Boilers		9.4	1.2	45	2.3	NAV
Wood						
Incineration - high efficiency[a]		440	NAV	130	NAV	NAV
Waste						
Mass Burn Waterwall		22	NAV	170	NAV	NAV
Combustors		NAV	NAV	NAV	NAV	NAV
MSW Boilers[a]		19	NAV	460	NAV	NAV

Source: US EPA (1995).
(a) Adapted from Radian, 1990.

TABLE 1-20
UTILITY EMISSION CONTROLS PERFORMANCE

Technology	Efficiency Loss[(a)] (%)	CO Reduction (%)	CH_4 Reduction (%)	NO_x Reduction (%)	N_2O Reduction (%)	NMVOCs Reduction (%)	Date Available[(b)]
Low Excess Air (LEA)	-0.5	+	+	15	NAV	NAV	1970
Overfire Air (OFA) - Coal	0.5	+	+	25	NAV	NAV	1970
OFA - Gas	1.25	+	+	40	NAV	NAV	1970
OFA - Oil	0.5	+	+	30	NAV	NAV	1970
Low NO_x Burner (LNB) - Coal	0.25	+	+	35	NAV	NAV	1980
LNB - Tangentially Fired	0.25	+	+	35	NAV	NAV	1980
LNB - Oil	0.25	+	+	35	NAV	NAV	1980
LNB - Gas	0.25	+	+	50	NAV	NAV	1980
Cyclone Combustion Modification	0.5	NAV	NAV	40	NAV	NAV	1990
Ammonia Injection	0.5	+	+	60	NAV	NAV	1985
Selective Catalytic Reduction (SCR) - Coal	1	8	+	80	NAV	NAV	1985
SCR - Oil, AFBC	1	8	+	80	NAV	NAV	1985
SCR - Gas	1	8	+	80	60	NAV	1985
Water Injection - Gas Turbine Simple Cycle	1	+	+	70	NAV	NAV	1975
SCR - Gas Turbine	1	8	+	80	60	NAV	1985
Retrofit LEA	-0.5	+	+	15	NAV	NAV	1970
Retrofit OFA - Coal	0.5	+	+	25	NAV	NAV	1970
Retrofit OFA - Gas	1.25	+	+	40	NAV	NAV	1970
Retrofit OFA - Oil	0.5	+	+	30	NAV	NAV	1970
Retrofit LNB - Coal	0.25	+	+	35	NAV	NAV	1980
Retrofit LNB - Oil	0.25	+	+	35	NAV	NAV	1980
Retrofit LNB - Gas	0.25	+	+	50	NAV	NAV	1980
Burners Out of Service	0.5	+	+	30	NAV	NAV	1975

(a) Efficiency loss as a percentage of end-user energy conversion efficiency (ratio of energy output to energy input for each technology) due to the addition of an emission control technology. Negative loss indicates an efficiency improvement.

(b) Date technology is assumed to be commercially available.

Note: A "+" indicates negligible reduction.

Source: Radian, 1990.

TABLE 1-21
INDUSTRIAL BOILER EMISSION CONTROLS PERFORMANCE

Technology	Efficiency Loss[a] (%)	CO Reduction (%)	CH_4 Reduction (%)	NO_x Reduction (%)	N_2O Reduction (%)	NMVOCs Reduction (%)	Date Available[b]
Low Excess Air (LEA)	-0.5	+	+	15	NAV	NAV	1970
Overfire Air (OFA) - Coal	0.5	+	+	25	NAV	NAV	1970
OFA - Gas	1.25	+	+	40	NAV	NAV	1970
OFA - Oil	0.5	+	+	30	NAV	NAV	1970
Low NO_x Burner (LNB) - Coal	0.25	+	+	35	NAV	NAV	1980
LNB - Oil	0.25	+	+	35	NAV	NAV	1980
LNB - Gas	0.25	+	+	50	NAV	NAV	1980
Flue Gas Recirculation	0.5	+	+	40	NAV	NAV	1975
Ammonia Injection	0.5	+	+	60	NAV	NAV	1985
Selective Catalytic Reduction (SCR) - Coal	1	8	+	80	NAV	NAV	1985
SCR - Oil, AFBC	1	8	+	80	NAV	NAV	1985
SCR - Gas	1	8	+	80	60	NAV	1985
Retrofit LEA	-0.5	+	+	15	NAV	NAV	1970
Retrofit OFA - Coal	0.5	+	+	25	NAV	NAV	1970
Retrofit OFA - Gas	1.25	+	+	40	NAV	NAV	1970
Retrofit OFA - Oil	0.5	+	+	30	NAV	NAV	1970
Retrofit LNB - Coal	0.25	+	+	35	NAV	NAV	1980
Retrofit LNB - Oil	0.25	+	+	35	NAV	NAV	1980
Retrofit LNB - Gas	0.25	+	+	50	NAV	NAV	1980

(a) Efficiency loss as a percentage of end-user energy conversion efficiency (ratio of energy output to energy input for each technology) due to the addition of an emission control technology. Negative loss indicates an efficiency improvement.

(b) Date technology is assumed to be commercially available.

Note: A "+" indicates negligible reduction.

Source: Radian, 1990.

TABLE 1-22
KILN, OVENS, AND DRYERS EMISSION CONTROLS PERFORMANCE

Technology	Efficiency Loss[a] (%)	CO Reduction (%)	CH_4 Reduction (%)	NO_x Reduction (%)	N_2O Reduction (%)	NMVOCs Reduction (%)	Date Available[b]
LEA - Kilns, Dryers	-6.4	+	+	14	NAV	NAV	1980
LNB - Kilns, Dryers	0	+	+	35	NAV	NAV	1985
SCR - Coke Oven	1.0	8	+	80	60	NAV	1979
Nitrogen Injection	NAV	NAV	NAV	30	NAV	NAV	1990
Fuel Staging	NAV	NAV	NAV	50	NAV	NAV	1995

(a) Efficiency loss as a percentage of end-user energy conversion efficiency (ratio of energy output to energy input for each technology) due to the addition of an emission control technology. Negative loss indicates an efficiency improvement.

(b) Date technology is assumed to be commercially available.

Note: A "+" indicates negligible reduction.

Source: Radian, 1990.