



TABLE 1-2 (CONTINUED)
1990 COUNTRY-SPECIFIC NET CALORIFIC VALUES FOR OECD COUNTRIES
 (Terajoule per kilotonne)

	Australia	Austria	Belgium	Canada	Den- mark	Finland	France	Germany	Greece	Iceland	Ireland	Italy
OIL												
Crude Oil	43.21	42.75	42.75	42.79	42.71	42.66	42.75	42.75	42.75	-	42.83	42.75
NGL	45.22	45.22	-	45.22	-	-	45.22	-	45.22	-	-	45.22
Refinery Feedst.	42.50	42.50	42.50	42.50	42.50	42.50	42.50	42.50	42.50	-	42.50	42.50
COAL												
Coking Coal												
Production	28.34	-	-	28.78	-	-	28.91	28.96	-	-	-	-
Imports	-	28.00	29.31	27.55	-	34.33	30.50	28.96	-	27.44	29.10	30.97
Exports	28.21	-	-	28.78	-	-	-	28.96	-	-	-	-
Other Bituminous Coal and Anthracite^(a)												
Production	24.39	-	25.00	28.78	-	-	26.71	24.96	-	-	26.13	26.16
Imports	-	28.00	25.00	27.55	26.09	26.38	25.52	26.52	27.21	25.85	29.98	26.16
Exports	25.65	-	25.00	28.78	26.09	-	26.43	31.71	-	-	26.13	-
Sub-Bituminous Coal												
Production	17.87	-	18.06	17.38	-	-	-	-	-	-	-	-
Imports	-	-	-	-	-	-	-	-	-	-	-	-
Exports	-	-	18.20	-	-	-	-	-	-	-	-	-
Lignite												
Production	9.31	10.90	-	14.25	-	-	17.94	8.41	5.74	-	-	10.47
Imports	-	10.90	21.56	-	-	-	17.94	14.88	-	-	19.82	10.47
Exports	-	10.90	-	14.25	-	-	-	8.40	-	-	-	-
Coal Products												
Patent Fuel/BKB	21.00	19.30	23.81	-	18.27	-	28.80	20.64	15.28	-	20.98	-
Coke Oven/Gas Coke	25.65	28.20	29.31	27.39	31.84	28.89	28.71	28.65	29.30	26.65	32.66	29.30

(a) In IEA statistics Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.
 The NCVs for oil and coal are those used by the IEA in the construction of energy balances.
 The NCVs for coal product groupings listed are calculated from the values of their constituents.
 Source: OECD/IEA, 1993a.

TABLE 1-2 (CONTINUED)
1990 COUNTRY-SPECIFIC NET CALORIFIC VALUES FOR OECD COUNTRIES
 (Terajoule per kilotonne)

	Japan	Luxem- bourg	Nether- lands	NZ	Norway	Portugal	Spain	Sweden	Switzer- land	Turkey	UK	USA
OIL												
Crude Oil	42.62	-	42.71	43.12	42.96	42.71	42.66	42.75	42.96	42.79	42.83	42.71
NGL	46.05	-	45.22	46.05	45.22	-	45.22	-	-	-	46.89	45.22
Refinery Feedst.	42.50	-	42.50	44.80	42.50	42.50	42.50	42.50	42.50	42.50	42.50	42.50
COAL												
Coking Coal												
Production	30.63	-	-	28.00	-	-	29.16	-	-	33.49	29.27	29.68
Imports	30.23	-	29.30	28.00	-	29.30	30.14	30.00	-	33.49	30.07	-
Exports	-	-	-	28.00	-	-	-	-	-	-	29.27	29.68
Other Bituminous Coal and Anthracite^(a)												
Production	23.07	-	-	26.00	28.10	-	21.07	14.24	-	29.30	24.11	26.66
Imports	24.66	29.30	29.30	-	28.10	26.59	25.54	26.98	28.05	27.21	26.31	27.69
Exports	-	-	29.30	-	28.10	-	23.00	26.98	28.05	-	27.53	28.09
Sub-Bituminous Coal												
Production	-	-	-	21.30	-	17.16	11.35	-	-	-	-	19.43
Imports	-	-	-	-	-	-	11.35	-	-	-	-	-
Exports	-	-	-	-	-	-	-	-	-	-	-	-
Lignite												
Production	-	-	-	14.10	-	-	7.84	-	-	9.63	-	14.19
Imports	-	20.03	20.00	-	-	-	-	8.37	-	12.56	-	-
Exports	-	-	20.00	-	-	-	-	-	-	-	-	14.19
Coal Products												
Patent Fuel/BKB	27.05	20.10	23.53	-	-	-	20.31	20.10	21.76	20.93	26.26	-
Coke Oven/Gas Coke	28.64	28.50	28.50	-	28.50	28.05	30.14	28.05	28.05	29.28	26.54	27.47
(a) In IEA statistics Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination. The NCVs for oil and coal are those used by the IEA in the construction of energy balances. The NCVs for coal product groupings listed are calculated from the values of their constituents. Source: OECD/IEA, 1993a.												



TABLE 1-3 NET CALORIFIC VALUES FOR OTHER FUELS (TJ/10 ³ tonnes)	
Refined Petroleum Products	
Gasoline (aviation and auto)	44.80
Jet Kerosene	44.59
Other Kerosene	44.75
Shale Oil	36.00
Gas/Diesel Oil	43.33
Residual Fuel Oil	40.19
LPG	47.31
Ethane	47.49
Naphtha	45.01
Bitumen	40.19
Lubricants	40.19
Petroleum Coke	31.00
Refinery Feedstocks	44.80
Refinery Gas	48.15
Other Oil Products	40.19
Other Products	
Coal Oils and Tars derived from Coking Coal	28.00
Oil Shale	9.40
Orimulsion	27.50
Source: OECD/IEA, Paris, 1996a.	

Select Carbon Emission Factors and Estimate Carbon Content

Carbon emission factors may vary considerably both among and within primary fuel types:

- For natural gas, the carbon emission factor depends on the composition of the gas which, in its delivered state, is primarily methane, but can include small quantities of ethane, propane, butane, and heavier hydrocarbons. Natural gas flared at the production site will usually be "wet", i.e., containing far larger amounts of non-methane hydrocarbons. The carbon emission factor will be correspondingly different.
- Carbon content per unit of energy is usually less for light refined products such as gasoline than for heavier products such as residual fuel oil.
- For coal, carbon emissions per tonne vary considerably depending on the coal's composition of carbon, hydrogen, sulphur, ash, oxygen, and nitrogen.

Estimates of carbon emission factors for fuels from several studies are summarised in Table 1-4.

Study	Anthracite	Bit. Coal	Sub-Bit. Coal	Lignite	Peat	
Marland & Rotty (1984)		25.5 ^(a)				
Marland & Pippin (1990)		25.4 ^(a)				
Grubb (1989)	26.8 ^(a)	25.8 ^(a)		27.6 ^(a)	28.9 ^(a)	
OECD (1991)		25.8 ^(a,b)				
Study	Crude Oil	Gasoline	Kerosene	Gas/Diesel Oil	Fuel Oil	Natural Gas
Marland & Rotty (1984)	21.0 ^(a)				15.2 ^(a)	
Marland & Pippin (1990)	21.0 ^(a)	19.4 ^(a)	19.4 ^(a)	19.9 ^(a)	21.1 ^(a,c)	15.3 ^(a)
Grubb (1989)	20.0 ^(a)	18.9 ^(a)	19.5 ^(a)	20.0 ^(a)	21.1 ^(a)	15.3 ^(a)
OECD (1991)	20.0					15.3
<p>(a) Values were originally based on gross calorific value; they were converted to net calorific value by assuming a 5% difference in calorific value for coal and oil, and 10% for natural gas. These percentage adjustments are the IEA assumptions on how to convert from gross to net calorific values.</p> <p>(b) Average value for all coal: sub-bituminous through anthracite.</p> <p>(c) Midpoint of range from 20.7 for light fuel oil (#4 fuel oil) to 21.6 for residual fuel oil (#6 fuel oil).</p>						

One approach for estimating the carbon emission factors was presented by Marland and Rotty (1984). For natural gas, the carbon emission factor was based on the actual composition of dry natural gas. They sampled the composition of natural gas from 19 countries and then calculated a weighted average global gas composition, breaking the gas out into methane, ethane, propane, other hydrocarbons, CO₂ and other gases. The composition of the gas then determined both the calorific values of the gas and the carbon content. The carbon emission factor of the gas (t C/terajoule, using gross calorific values) was expressed using the following relationship:

$$C_g = 13.708 + (0.0828 \times 10^{-3}) \times (H_v - 37\,234)$$

where C_g is the carbon emission factor of the gas in t C/terajoule (TJ) and H_v is the calorific value of the gas (gross calorific value, see OECD/IEA, 1996a) in kJ/cubic metre. The coefficients of the equation (13.708, 0.0828×10^{-3} , and 37 234) were estimated using regression analysis based on data from the 19 countries. The carbon content of oil was assumed to be a function of the API gravity: using an estimate of world average API gravity of $32.5^{\circ} \pm 2^{\circ}$, they estimated a composition of 85 ± 1 per cent carbon. Converting this to units of carbon per terajoule yielded an estimate of 21.0 t C/TJ on a net calorific value basis (assuming 42.62 terajoules per kilotonne, gross calorific value, as reported in Marland & Rotty, 1984). For coal, the literature suggested that the carbon content of coal was predominantly a function of the energy content (calorific value) and that the carbon content on a per tonne coal-equivalent basis was around 74.6 ± 2 per cent (Marland and Rotty 1984). The carbon emission factor was estimated to be 25.5 t C/TJ.

The approach used by Grubb (1989) to estimate carbon emission factors is very similar but based on more recent research. All carbon emission factors were originally reported on a gross calorific value basis, but are converted here to a net calorific value basis. He provides carbon factors for methane, ethane, propane, and butane and using data from



Marland and Rotty (1984), estimates an average emission factor for natural gas of 15.3 t C/TJ \pm 1 per cent. For oil and some refined petroleum products the estimates are based on data from the literature, as summarised in Table 1-4. The carbon emission factor of coal, excluding anthracite, was defined as:

$$C_c = 32.15 - (0.234 \times H_v)$$

where C_c is the carbon emission factor in t C/TJ and H_v is the gross calorific value of the coal when the calorific value is from 31 to 37 TJ/kilotonne on a dry mineral matter free (dmf) basis. Anthracites fall outside this range and a value of 26.8 t C/TJ is used.

Since the publication of the original OECD Background Document (OECD 1991), additional information has been made available on carbon emission factors. At an IPCC-sponsored workshop in October 1992 (IPCC/OECD, 1993), experts recommended several revised emission factors based on national inventory submissions to the OECD. Additional emission factors were also made available based on the work of the expert group on GHG Emissions from Fuel Combustion during Phase II of the IPCC/OECD/IEA Programme on National GHG Inventories in 1996.

The IPCC Reference Approach relies primarily on the emission factors from Grubb (1989), with additions from other studies as discussed above, to estimate total carbon content. The suggested carbon emission factors are listed in Table 1-1. The basic formula for estimating total carbon content is:

$$\begin{aligned} \text{Total Carbon Content (Gg C)} = \\ \sum \text{ Apparent Energy Consumption (by fuel type in TJ)} \\ \times \text{ Carbon emission factor (by fuel type in t C/TJ)} \\ \times 10^{-3} \end{aligned}$$

Apparent consumption of the fuels is estimated in Table 1-1 (Column 6). The carbon emission factors for the fuels are average values based on net calorific value. This approach has been recommended by the IPCC because it explicitly treats each major fuel type differently according to its carbon emission factor. When countries use local values for the carbon emission factors they should note the differences from the default values and provide documentation supporting the values used in the national inventory calculations.

Estimate Carbon Stored in Products

The next step is to estimate the amount of fossil fuel carbon that is stored in non-energy products and the portion of this carbon expected to oxidise over a long time period (e.g., greater than 20 years). All fossil fuels are used for non-energy purposes to some degree. Natural gas is used for ammonia production. LPGs are used for a number of purposes, including production of solvents and synthetic rubber. A wide variety of products is produced from oil refineries, including asphalt, naphthas and lubricants. Two by-products of the coking process, oils and tars, are used in the chemical industry.

Not all non-energy uses of fossil fuels, however, result in storage of carbon. For example, the carbon from natural gas used in ammonia production is oxidised quickly. Many products from the chemical and refining industries are burned or decompose within a few years. Several approaches for estimating the portion of carbon stored in products are reviewed in Box 2.

Box 2

APPROACHES FOR ESTIMATING CARBON STORED IN PRODUCTS

The approach used by Marland and Rotty (1984) relied on historical data for determining non-energy applications and varied depending on fossil fuel type. For natural gas they assume that close to 1/3 of the carbon used for non-energy purposes (equivalent to 1 per cent of total carbon from natural gas production) does not oxidise over long periods of time. For oil products they assume that some portion of LPG, ethane, naphthas, asphalt and lubricants does not oxidise quickly. Specifically, they assume that about 50 per cent of LPG and ethane from gas processing plants is sold for chemical and industrial uses and that 80 per cent of this amount, or 40 per cent of all LPG and ethane, goes into products that store the carbon. About 80 per cent of the carbon in naphthas is assumed to end up in products such as plastics, tires, and fabrics and oxidises slowly. All of the carbon in asphalt is assumed to remain unoxidised for long periods, while about 50 per cent of the carbon in lubricants is assumed to remain unoxidised. For coal they assume that on average 5.91 per cent of coal going to coke plants ends up as light oil and crude tar, with 75 per cent of the carbon in these products remaining unoxidised for long periods.

Grubb (1989) basically uses the Marland and Rotty (1984) approach, but suggests several changes, including higher estimates of methane losses during production and transportation of natural gas to market and a wide range of estimates concerning the fraction of carbon in refinery products that remain unoxidised. He does use Marland and Rotty's estimate of the amount of carbon in coal that does not oxidise, but also quantifies the amount of carbon emissions from SO₂ scrubbing (in which CO₂ is released during the chemical interactions in the desulphurisation process) using the formula: (% sulphur by weight) x (coal consumption) x 12/32.

Okken and Kram (1990) introduce the concept of actual and potential emissions of CO₂ where potential emissions are defined as carbon that is stored in products from non-energy uses or by-products from combustion and actual emissions as all carbon from fuels that are emitted immediately or within a short period of time. Actual emissions plus potential emissions equal total carbon in the fuels. They assume that carbon from the following non-energy uses of fossil fuels oxidises quickly: fertiliser production (ammonia), lubricants, detergents, volatile organic solvents, etc. Carbon from the following non-energy uses of fossil fuels remains stored for long periods of time (in some cases, hundreds of years): plastics, rubber, bitumen, formaldehyde, and silicon carbide.

For the IPCC Reference Approach, the suggested formula for estimating carbon stored in products for each country is:

$$\begin{aligned} \text{Total Carbon Stored (Gg C)} = & \\ & \text{Non-Energy Use (10}^3 \text{ t)} \\ & \times \text{Conversion Factor (TJ/10}^3 \text{ t)} \\ & \times \text{Emission Factor (t C/TJ)} \\ & \times \text{Fraction Carbon Stored} \\ & \times 10^{-3} \end{aligned}$$



Most of the suggested categories conform to those used by Marland and Rotty (1984) and include naphthas, bitumen (asphalt), lubricants, LPG, and coal oils and tars. The data available from the UN reports (e.g., 1996) correspond to these categories, with the exception of coal oils and tars, which are not reported.

The assumptions of 75 per cent for naphtha as a feedstock and 50 per cent for gas/diesel oil as a feedstock, used in Table 1-5 (Column 6) should be viewed as potential overestimates, since not all of the carbon from the intermediate products will be stored. For example, carbon emissions may occur due to losses in the production of final products or incineration of final products. At this time these percentages can be used as the upper bound when determining stored carbon.

This suggested approach for estimating carbon stored in products is illustrated in Table 1-5. Whenever possible, countries should substitute assumptions that represent more accurately the practices within their own countries and provide documentation for these assumptions. The resulting estimates from Table 1-5 (Column 7) should be subtracted from carbon content of apparent consumption to determine net carbon emissions that could be oxidised. This calculation is done by entering the values from Table 1-5 (Column 7) for the relevant fuels/products into Table 1-1 (Column 11). In Table 1-1, carbon stored in products is subtracted from total carbon in the fuels ("carbon content") to get net carbon available for emission ("net carbon emissions").

Currently the fraction of carbon stored applied to the carbon content of the fuels used for product manufacture takes into account the release of carbon from the use or destruction of the products in the short term. The fraction is therefore lower than the fraction of carbon entering the products (see Box 2). The emissions resulting from the use or destruction of the products may occur in:

- industrial processes – both the production of non-fuel products from energy feedstocks, and the emissions from use of these products in industrial processes (e.g., oxidation of anodes made from petroleum coke which occurs during aluminium production);
- other end uses of products (e.g., lubricants oxidised in transportation);
- waste disposal – particularly incineration of plastics and other fossil fuel based products.

	1	2	3	4	5	6	7
	Estimated Fuel Quantities ^(a)	Conversion Factor	Estimated Fuel Quantities ^(b)	Emission Factor	Carbon Content ^(c)	Fraction Carbon Stored	Carbon Stored ^(d)
Product/Fuel ^(e)	(Original Units)	TJ/Units	(TJ)	(t C/TJ)	(Gg C)		(Gg C)
Lubricants	calc	Table 1-3	calc	Table 1-1	calc	0.50	calc
Bitumen	calc	Table 1-3	calc	Table 1-1	calc	1.0	calc
Coal Oils and Tars from Coking Coal	calc ^(f)	Table 1-3	calc	Table 1-1 ^(g)	calc	0.75	calc
Naphtha as Feedstock	calc	Table 1-3	calc	Table 1-1	calc	0.75	calc
Gas/Diesel Oil as Feedstock	calc	Table 1-3	calc	Table 1-1	calc	0.50	calc
Natural Gas as Feedstock	calc	Table 1-3	calc	Table 1-1	calc	0.33	calc
LPG as Feedstock	calc	Table 1-3	calc	Table 1-1	calc	0.80	calc
Ethane as Feedstock	calc	Table 1-3	calc	Table 1-1	calc	0.80	calc

(a) Either Apparent Consumption plus domestic (manufactured) production, or Feedstock Use.
(b) Estimated Fuel Quantities in TJ (Col. 3) equals Estimated Fuel Quantities (Col. 1) times a Conversion Factor (Col. 2).
(c) Carbon Content (Col. 5) equals Estimated Fuel Quantities in TJ (Col. 3) times an Emission Factor (Col. 4).
(d) Carbon Stored (Col. 7) equals Carbon Content (Col. 5) times Fraction Carbon Stored (Col. 6) divided by 10³.
(e) This is an incomplete list of products/fuels which account for the majority of carbon stored. Where data are available for other fuels, the estimation of stored carbon is strongly encouraged.
(f) Use 6% of apparent consumption of Coking Coal.
(g) Use the emission factor for coking coal (25.8 t C/TJ).

Estimate Carbon Unoxidised During Fuel Use

A small part of the fuel carbon entering combustion escapes oxidation but the majority of this carbon is later oxidised in the atmosphere. It is assumed that the carbon that remains unoxidised is stored indefinitely. Based on work by Marland and Rotty (1984), since 1991 the IPCC has been recommending that 1 per cent of the carbon in fossil fuels would remain unoxidised. This assumption was based on the following findings from Marland and Rotty for the amount unoxidised:

- For natural gas, less than 1 per cent of the carbon is unoxidised during combustion and remains as soot in the burner, stack, or in the environment.
- For oil 1.5% ±1% passes through the burners and is deposited in the environment without being oxidised. This estimate is based on 1976 US statistics of emissions of hydrocarbons and total suspended particulates.
- For coal 1% ±1% of carbon supplied to furnaces is discharged unoxidised, primarily in the ash.

However, several countries have commented that the amount of carbon remaining unoxidised is more variable than indicated by the 1 per cent assumption across all fuels. For example, it has been noted that the amount of unburnt carbon varies depending on several factors, including type of fuel consumed, type of combustion technology, age of the equipment, and operation and maintenance practices.

Information submitted by the Coal Industry Advisory Board of the OECD (Summers 1993), provided the following observations for coal combustion technologies:



- Unoxidised carbon from electric power stations in Australia averaged about 1 per cent. Test results from stoker-fired industrial boilers, however, were higher, with unoxidised carbon amounting to 1 to 12 per cent of total carbon with coals containing from 8 to 23 per cent ash. As average values, 2 per cent carbon loss was suggested for best practices, 5 per cent carbon loss for average practices, and 10 per cent carbon loss for worst practices. In those cases when coal is used in the commercial or residential sectors, carbon losses would be on the order of 5 to 10 per cent (Summers, 1993).
- In related work British Coal has provided information on the percentage of unburnt carbon for different coal combustion technologies:

Pulverised Coal	1.6%
Travelling Grate Stoker	2.7-5.4%
Underfeed Stoker	4.0-6.6%
Domestic Open Fire	0.6-1.2%
Shallow Bed AFBC ¹⁰	Up to 4.0%
PFBC/CFBC ¹⁰	3.0%

- Evaluations at natural gas-fired boiler installations indicate that combustion efficiency is often 99.9 per cent at units reasonably well-maintained.

It is clear from the available information that a single global default assumption of 1 per cent unoxidised carbon is not always accurate. While some additional information is available to refine the assumptions for this portion of the methodology, most of the new information requires some level of detail on the type of technology in which the fuel is combusted or information on which sector is consuming the fuel. The Reference Approach requires data only on the amount of fuels consumed in a country, not data by technology type or sector of the economy. As a result, based on the information available at this point, the default values presented in Table 1-6 are recommended for the percentage of carbon oxidised during combustion by fuel. It should be recognised that the value for coal is highly variable based on fuel quality and technology types. National experts are encouraged to vary this assumption if they have data on these factors, suggesting that different average values for their countries are appropriate. It is clear from the information available at this time that additional research should be conducted on this topic.

Coal ^(a)	0.98
Oil and Oil Products	0.99
Gas	0.995
Peat for electricity generation ^(b)	0.99
^(a) This figure is a global average but varies for different types of coal, and can be as low as 0.91.	
^(b) The fraction for peat used in households may be much lower.	

¹⁰ AFBC = Advanced Fluidised Bed Combustion
CFBC = Circulating Fluidised Bed Combustion
PFBC = Pressurised Fluidised Bed Combustion

Convert carbon emissions to full molecular weight CO₂

Net carbon emissions (Column 12 in Table 1-1) are then multiplied by the fraction of carbon oxidised to give actual carbon emissions (Column 13 of Table 1-1), and then summed across all fuel types, to determine the total amount of carbon oxidised from the combustion of fuel. To express the results as carbon dioxide (CO₂), total carbon oxidised should be multiplied by the molecular weight ratio of CO₂ to C, (44/12).

1.4.1.2 EMISSIONS BY SOURCE CATEGORIES

A sectoral breakdown of national CO₂ emissions using the defined IPCC source categories is needed for monitoring and abatement policy discussions. The IPCC Reference Approach provides a rapid method to estimate the total CO₂ emissions from fuels supplied to the country but it does not break down the emissions by sector. The development of a Tier 1 method giving non-CO₂ GHG emissions by sector (Section 1.4.2) has been extended to CO₂ so that sectoral information can be obtained simply for this gas. However, the range of the carbon emission factors for fuels and the special consideration given to CO₂ emissions from biofuels mean that the calculations for CO₂ differ in a number of respects from those used for the non-CO₂ gases.

The more detailed calculations used for this approach are essentially similar in content to those used for the Reference Approach.

The formula is:

$$\begin{array}{c} \text{carbon emissions} \\ = \\ \sum \text{fuel consumption expressed in energy units (TJ) for each sector} \\ \times \text{carbon emission factor} \\ - \text{carbon stored} \\ \times \text{fraction oxidised} \end{array}$$

There are seven key considerations when calculating CO₂ emissions by sector some of which have already been discussed for the Reference Approach:

- Identification of the quantities of fuels consumed (combusted) in energy industries;
- A clear understanding of how emissions from electricity generation and heat are treated;
- Identification of the fraction of carbon released during the use of fuels for non-energy purposes;
- Adjustments for carbon unoxidised;
- Identification of the quantities of fuels used for international transport;
- Separation of the emissions from the combustion of biofuels;
- Separation of the quantities of fuels used in the Agriculture/Forestry/Fisheries between mobile sources and stationary plant.



Quantities of fuels combusted in the energy industries.

For emission calculations there are three principal groups of activities involving fuels in the energy and transformation sector:

- (i) The transformation of primary fuels into secondary fuels by physical or chemical processes not involving combustion of the primary fuel. For example, manufacture of petroleum products from crude oil.
- (ii) The production of heat for sale or for electricity generation.
- (iii) Combustion of fuels to support the main energy extraction or production business of the enterprise. For example, use of refinery gas for heating distillation columns, use of colliery methane at mines for heating purposes.

Activities within the first group are mainly those of refining and manufacture of solid fuels and derived gases. By definition, group (i) does not lead to fuel combustion emissions. Only fuels entering the activities in groups (ii) and (iii) should be considered for the calculation of emissions.

The underlying model of carbon flow which drives the reporting for the energy and transformation sector is that primary fuel carbon entering group (i) will appear either in the secondary products or be lost as fugitive emissions which are reported separately in Category 1B, Fugitive Emissions from Fuels. Carbon in secondary products will be partly or entirely stored or combusted either:

- 1) within the transformation industry as a group (iii) activity (e.g, refinery fuel or coke oven gas for heating coke ovens), or
- 2) as a group (ii) activity, or
- 3) by final consumers outside the energy industry.

In short therefore, because the pathways for carbon *leaving* a transformation process are covered by reporting on the worksheets in Module 1, there is no need to report quantities of primary fuels used exclusively for refining or solid fuel manufacture, notably, crude oil and coking coal. If, however, a country does use crude oil for electricity generation, for example, then the relevant quantity should be reported.

The scope of the activities to be included under group (ii) also needs further definition and this will be considered now.

Generation of electricity and heat

The Overview to this chapter (Section 1.1) describes the steps taken to harmonise reporting and inventory compilation required from those countries completing inventories according to both IPCC and EMEP/CORINAIR reporting requirements. An important step towards harmonisation has been the decision to align the IPCC reporting of emissions from electricity and heat generation by autoproducers (see Box 3) with that of CORINAIR.

In the 1995 *Guidelines* emissions from autoproducers were included with those from main power producers (referred to as "Public Electricity and Heat"). In this edition of the *Guidelines*, emissions from autoproduction are attributed to the industrial or commercial branches in which the generation activity occurs. Emissions reported under "Public Electricity and Heat" should be those from main power producers only.

Box 3**AUTOPRODUCERS**

An autoproducer of electricity or heat is an enterprise which generates electricity or sells heat as a secondary activity, i.e., not as its main business. This should be contrasted with main power producers who generate electricity or who sell heat as their main business (primary activity) and may be publicly or privately owned. Supplies from main power producers are referred to as "Public" electricity and heat supply although an increasing part of public supply is being met by autoproducers.

Wherever possible the quantities of fuel used for, and the resulting emissions from, autoproduction should be identified in the worksheets used for this calculation. The worksheets make provision for this. As a growing amount of public electricity supply comes from autoproduction, calculation of the related emissions will assist identification of total emissions from electricity generation.

Carbon release during the non-energy use of fuels

The calculation of carbon content of fuels consumed, as a step for the estimation of the CO₂ emissions from fuel combustion, must be adjusted for the quantities of carbon which are stored within products made from fuels used as raw materials or within products used for their physical properties rather than combusted (e.g., bitumen or lubricants). The approach used to do this and the types of fuels involved are fully discussed under "Stored Carbon" in Section 1.4.1.1 and the arguments will not be repeated. There are two aspects of this adjustment, however, which need to be mentioned explicitly here because the calculation of carbon release at the level of fuel deliveries permits certain simplifications not available at the level of fuel supplies used for the Reference Approach. This arises because the Reference Approach estimates emissions from the supply of primary fuels and external trade in secondary fuels whereas the sectoral approach uses the carbon content of delivered fuels from which the full quantities of fuels entering long-term storage may be identified.

- 1 Bitumen and coal tars are usually not combusted but used in a manner which causes most of the carbon content to enter long-term storage. As a result, these products are excluded from the calculation of fuel combustion emissions and do not feature in the list of commodities on the worksheet.
- 2 Other fuels that are only partly combusted are included within the worksheet and the fraction of carbon entering long-term storage estimated by means of a carbon storage factor. A similar method is used for the Reference Approach. In the present sectoral calculation, however, no special steps are required to obtain deliveries data as the approach relies on them for all of its calculations.

Adjustments For Carbon Unoxidised

As discussed above under the Reference Approach, the amount of carbon that may remain unoxidised from combustion activities can vary for many reasons, including type of fuel consumed, type of combustion technology, age of the equipment, and operation and maintenance practices. Since the present approach relies on more disaggregated fuel consumption data, it is possible to specify the assumptions for unoxidised carbon by application. Unless other data are available, countries should use as default values the assumptions recommended in the Reference Approach: 2 per cent of carbon in fuel consumed is unoxidised for coal, 1 per cent for oil-derived fuels, 0.5 per cent for natural



gas and 1 per cent for peat used for electricity generation. In addition, the following assumptions (from Summers, 1993) are recommended:

- For stoker-fired industrial boilers an average value for carbon unoxidised is 5 per cent. If countries believe that their operation and maintenance procedures achieve maximum efficiency, a 2 per cent carbon loss is suggested. If these procedures are believed to lead to very poor efficiency, then a 10 per cent carbon loss is recommended.
- In those cases when coal is used in the commercial or residential sectors, the assumption for unoxidised carbon should be 5 per cent.

Clearly, much additional research needs to be done in this area. These adjustments are suggested as initial default values. As more work is done, countries are encouraged to report any additional information they may have to refine understanding of the amount of carbon unoxidised in various applications.

Fuels used for international transport

The exclusion from national totals of emissions from (bunker) fuels used for international marine and air transport has been discussed in Section 1.4.1.1, Reference Approach. As in that approach, the emissions from international bunkers should not be omitted entirely but reported separately on the worksheet. The definitions of national and international movements for ships and aircraft are covered under the "Definition of Source Categories" (Energy) in Volume 1, *Reporting Instructions*.

Combustion of biofuels

CO₂ emissions from the combustion of biomass fuels are not to be included in the total national CO₂ emissions but should be reported separately on the worksheet.

Fuel use for mobile sources and stationary plant in the Agriculture/Forestry/Fisheries sector

The separation of fuel combustion between the two types of combustion sources in this sector has been introduced to permit the aggregation of CO₂ emissions from them with the emissions of the non-CO₂ gases. Whatever methods are used for estimating the quantities of fuels used by these two types when calculating the non-CO₂ emissions from this sector should be used for CO₂. Delivery statistics do not usually distinguish between combustion plant types in any economic activity sector.

1.4.2 Non-CO₂ Emissions

1.4.2.1 METHANE (CH₄) EMISSIONS FROM FUEL COMBUSTION

The contribution of fuel combustion to global emissions of methane is minor and the uncertainty is high. For these reasons, an aggregated fuel/sector split is sufficient for a Tier 1 approach, although exact product detail needs to be determined for CH₄ from biomass combustion. Fuel wood, charcoal, agricultural residues, agricultural waste and municipal waste combustion is by far the major contributor to CH₄ emissions within the fuel combustion group. Traditional charcoal making, which is a typical smouldering process, is a large source of methane which should be reported under Fugitive Emissions

from Energy. Consequently, CH₄ emissions from developing countries with large biomass consumption could be significant.

Methane is produced in small quantities from fuel combustion due to incomplete combustion of hydrocarbons in fuel. The production of methane is dependent on the temperature in the boiler/stove. In large, efficient combustion facilities and industrial applications, the emission rate is very low, with utility emission rates being less than 1 per cent of average rates for residential coal combustion. In smaller combustion sources, emission rates are higher, particularly when smouldering occurs. The highest rates of methane emissions from fuel combustion occur in residential applications (small stoves and open burning).

The CH₄ emissions from mobile sources are a function of the methane content of the motor fuel, the amount of hydrocarbons passing unburnt through the engine, the engine type, and any post-combustion controls. In uncontrolled engines the proportion of methane emissions is highest at low speeds and when the engine is idle. Poorly tuned engines may have a particularly high output of CH₄.

The general method for estimating CH₄ can be described as:

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

where:

EF = Emission Factor (kg/TJ);

Activity = Energy Input (TJ);

a = Fuel type; and

b = Sector-activity.

The following default emission factors have been developed by the IPCC based on the CORINAIR90 database, the CORINAIR 1994 default emission factors, the EDGAR Version 2.0 database, National Communications to the FCCC, Berdowski, et al. (1993a and 1993b), Radian Corporation (1990) and US EPA (1995). Additional research will need to be undertaken to further improve the quality of the emission factors.



TABLE 1-7
CH₄ DEFAULT (UNCONTROLLED) EMISSION FACTORS (IN KG/TJ)

		Coal(a)	Natural Gas	Oil	Wood/ Wood Waste	Charcoal	Other Biomass and Wastes(c)	
Energy Industries		1	1	3	30 ^(b)	200 ^(b)	30	
Manufacturing Industries and Construction		10	5	2	30	200	30	
Transport	Aviation(d)			0.5				
	Road		50	Gasoline 20(e)	Diesel 5			
	Railways	10		5				
	Navigation	10		5				
Other Sectors	Commercial/Institutional	10	5	10	300	200	300	
	Residential	300	5	10	300	200	300	
	Agriculture/ Forestry/ Fishing	Stationary	300	5	10	300	200	300
		Mobile		5	5			

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

(a) The emission factors for brown coal may be several times higher than those for hard coal.

(b) These factors are for fuel combustion in the energy industries. For charcoal production, please refer to Table 1-14, Default Non-CO₂ Emission Factors for Charcoal Production.

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

(d) In the cruise mode CH₄ emissions are assumed to be negligible (Wiesen et al., 1994). For LTO cycles only (i.e., below an altitude of 914 metres (3000 ft.)) the emission factor is 5 kg/TJ (10% of total VOC factor) (Olivier, 1991). Since globally about 10% of the total fuel is consumed in LTO cycles (Olivier, 1995), the resulting fleet averaged factor is 0.5 kg/TJ.

(e) Emission factors for 2-stroke engines may be three times higher than those for 4-stroke engines.

1.4.2.2 NITROUS OXIDE (N₂O) EMISSIONS FROM FUEL COMBUSTION

As with methane, the contribution of fuel combustion to global emissions of N₂O is minor and the uncertainty is high. Reliable emission factors are not yet available for all sources. For these reasons, an aggregated fuel/sector split is sufficient for a Tier 1 approach.

Nitrous oxide is produced directly from the combustion of fossil fuels. It has been determined that lower combustion temperatures (particularly below 1200 K) cause higher N₂O emissions with a maximum of N₂O production occurring around 1000 K. For combustion temperatures below 800 K or over 1200 K the emissions of N₂O are negligible (de Soete, 1993). Compared to emissions from conventional stationary combustion units, emissions of nitrous oxides from fluidised bed combustion are relatively high (Rentz et al., 1992). Nitrous oxide is formed by different catalytic reduction processes. For more detailed information on N₂O chemistry see de Soete (1993). The mechanisms of N₂O chemistry seem to be relatively well understood, but experimental data are limited.

N₂O emissions from vehicles have only recently been studied in detail. Global emissions from this source are still thought to be small relative to total anthropogenic emissions, but may be substantially higher when emission controls (especially catalysts on road vehicles) are used.

Published emission rates for non-commercial fuel combustion, in particular fuelwood, charcoal, agricultural wastes and dung are few and it is uncertain whether they are representative for global application (Olivier, 1993).

The general method for estimating N₂O can be described as:

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

where:

EF = Emission Factor (kg/TJ);

Activity = Energy Input (TJ);

a = Fuel type; and

b = Sector-activity.

The following default emission factors have been developed by the IPCC based on the CORINAIR90 database, the CORINAIR 1994 default emission factors, Radian Corporation (1990), the EDGAR Version 2.0 database, National Communications to the FCCC and de Soete (1993). Additional research will need to be undertaken to further improve the quality of the emission factors.

		Coal ^(a)	Natural Gas	Oil	Wood/ Wood Waste	Charcoal	Other Biomass and Wastes ^(c)	
Energy Industries		1.4	0.1	0.6	4 ^(b)	4 ^(b)	4	
Manufacturing Industries and Construction		1.4	0.1	0.6	4	4	4	
Transport	Aviation			2				
	Road		0.1	Gasoline	Diesel			
				0.6 ^(d)	0.6			
	Railways	1.4		0.6				
Navigation	1.4		0.6					
Other Sectors	Commercial/Institutional		1.4	0.1	0.6	4	1	4
	Residential		1.4	0.1	0.6	4	1	4
	Agriculture/ Forestry/ Fishing	Stationary	1.4	0.1	0.6	4	1	4
		Mobile		0.1	0.6			

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

(a) Brown coals may produce less N₂O than bituminous coals; some measurements have shown that N₂O emissions by hard coal combustion in power plants may be negligible. N₂O emissions from FBC are generally about 10 times higher than from boilers.

(b) These factors are for fuel combustion in the energy industries. For charcoal production, please refer to Table 1-14, Default Non-CO₂ Emission Factors for Charcoal Production.

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

(d) When there is a significant number of cars with 3-way catalysts in the country, road transport emission factors should be increased accordingly. Emission factors for 2-stroke engines may be three times higher than those for 4-stroke engines.



1.4.2.3 NITROGEN OXIDES (NO_x) EMISSIONS FROM FUEL COMBUSTION

Nitrogen oxides¹¹ are indirect greenhouse gases. They have been the target of environmental policies for their role in forming ozone (O₃), as well for their direct acidification effects.

Fuel combustion activities are the most significant anthropogenic source of NO_x. Within fuel combustion, the most important sources are the energy industries and mobile sources.

Generally two different formation mechanisms can be distinguished:

- formation of "fuel NO" from the conversion of chemically bound nitrogen in the fuel,
- formation of "thermal NO" from the fixation of the atmospheric nitrogen in the combustion process (Joint EMEP/CORINAIR, February 1996).

The majority of NO_x emitted from coal (80-90 per cent) is formed from fuel nitrogen. Thermal NO_x contributes less than 20 per cent and depends on combustion temperature. Excess air and high temperatures found in some firing configurations encourage the production of NO_x and these conditions are dependent on boiler type and operation of technology. For oil, the share of fuel NO_x may be less than 50 per cent. From gaseous fuels, only "thermal NO" is formed.

The NO_x emissions from mobile sources are related to the air-fuel mix and combustion temperatures, as well as pollution control equipment. For uncontrolled vehicles the proportion of NO_x emissions from a diesel-fuelled vehicle is generally lower than that for a gasoline-fuelled vehicle, and lower for a light-duty vehicle than that for a heavy-duty vehicle. Heavy-duty vehicles contribute significant emissions, which are difficult to reduce.

The general method for estimating NO_x can be described as:

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

where:

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

If abatement technologies for NO_x emissions reduction are used, the estimated emission factors of NO_x should be adjusted. Reduction efficiency (n) values for different types of abatement may vary; primary measures may range from 5 to 50 per cent (Joint EMEP/CORINAIR, 1996) and secondary measures from 50 to 95 per cent (Rentz, et al., 1992).

The following default values can be used for the reduction efficiency of primary measures in coal-fired installations when no information concerning the type of installation is available (Joint EMEP/CORINAIR, 1996).

¹¹ The convention in this document is that NO_x (NO+NO₂) emissions from fossil fuel combustion are expressed on a full molecular basis assuming that all NO_x emissions are emitted as NO₂.

Default Values for Reduction Efficiency (n)		
Type of primary measure	Hard coal	Lignite
no measure (mainly relevant for old installations)	0 %	0 %
old installations / optimised operation	15 - 20 %	15 %
old installation / retrofitted	50 %	50 %
new installation	40 %	35 %

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

Nitrogen oxides emission factors are available by detailed fuel/sector split for most of the fuel combustion sources. The following default emission factors have been developed by the IPCC based on the CORINAIR90 database, Radian Corporation (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 NO_x emissions.

TABLE 1-9 NO _x DEFAULT (UNCONTROLLED) EMISSION FACTORS (IN KG/TJ)(a)							
		Coal	Natural Gas	Oil	Wood/ Wood Waste	Charcoal	Other Biomass and Wastes(b)
Energy Industries		300	150	200	100(c)	100(c)	100
Manufacturing Industries and Construction		300	150	200	100	100	100
Transport	Aviation			300			
	Road		600	Gasoline			
				600	Diesel	800(d)	
	Railways	300		1200			
Navigation	300		1500				
Other Sectors	Commercial/Institutional		100	50	100	100	100
	Residential		100	50	100	100	100
	Agriculture/ Forestry/ Fishing	Stationary	100	50	100	100	100
		Mobile(e)		1000	1200		

Note: These factors are considered as the best available global default factors to date. The emission factors may be reduced to take into account reduction efficiencies, see default values for reduction efficiencies given above.

(a) NO_x emission factors for small combustion facilities tend to be much smaller than for large facilities due to lower combustion temperatures.

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

(c) These factors are for fuel combustion in the energy industries. For charcoal production, please refer to Table 1-14, Default Non-CO₂ Emission Factors for Charcoal Production.

(d) Assuming the major part is consumed by Heavy Duty Vehicles (HDV). When a country has a relatively high proportion of passenger cars running on diesel, the average emission factor may be substantially lower, as is indicated in Tables I-31 to I-34.

(e) The countries should, when possible, allocate the fuel consumption to road and off-road traffic. Emission factors for ships, boats, locomotives and farm equipment may be more than double those of duty vehicles.



1.4.2.4 CARBON MONOXIDE (CO) EMISSIONS FROM FUEL COMBUSTION

Carbon monoxide is an indirect greenhouse gas. The majority of CO emissions from fuel combustion come from motor vehicles. Another large contributor is the residential sector with small combustion equipment.

Carbon monoxide is an intermediate product of the combustion process and in particular under stoichiometric combustion conditions. The formation mechanism of CO is directly influenced by usage patterns, technology type and size, vintage, maintenance, and operation of the technology. Emission rates may vary by several orders of magnitude for facilities that are poorly operated or improperly maintained, such as might be the case of older units.

Size and age of unit may indicate that in smaller and older units, combustion is less controlled and hence emissions are likely to be higher than from larger and newer plants. In addition, many wood stoves (where there is a great variation in technology by geographic region) have particularly high emissions due to their largely inefficient combustion of fuel.

Carbon monoxide emissions from mobile sources are a function of the efficiency of combustion and post combustion emission controls. Emissions are highest when air-fuel mixtures are rich, with less oxygen than required for complete combustion. This occurs especially in idle, low speed, and cold start conditions in spark ignition engines.

The general method for estimating CO can be described as:

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

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.

Carbon monoxide emission factors are available by detailed fuel/sector split for most of the fuel combustion sources. The following default emission factors have been developed by the IPCC based on the CORINAIR90 database, Radian Corporation (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 CO emissions.

**TABLE 1-10
CO DEFAULT (UNCONTROLLED) EMISSION FACTORS (IN KG/TJ)**

		Coal	Natural Gas	Oil	Wood/ Wood Waste	Charcoal	Other Biomass and Wastes ^(a)	
Energy Industries		20	20	15	1000 ^(b)	1000 ^(b)	1000	
Manufacturing Industries and Construction		150	30	10	2000	4000	4000	
Transport	Aviation ^(c)			100				
	Road		400	Gasoline 8000 ^(d) Diesel 1000				
	Railways	150		1000				
	Navigation	150		1000				
Other Sectors	Commercial/Institutional	2000	50	20	5000	7000	5000	
	Residential	2000	50	20	5000	7000	5000	
	Agriculture/ Forestry/ Fishing	Stationary	2000	50	20	5000	7000	5000
		Mobile		400	1000			

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-CO₂ 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 ranges from 10 000 to 20 000 kg/TJ (default value: 15 000 kg/TJ).

(d) Generally the emission factors for gasoline vehicles are highest for motorcycles and passenger cars without emissions control equipment.

1.4.2.5 NON-METHANE VOLATILE ORGANIC COMPOUNDS (NMVOC) EMISSIONS FROM FUEL COMBUSTION

Non-Methane Volatile Organic Compounds¹² are indirect greenhouse gases.

The most important sources of NMVOCs from fuel combustion activities are mobile sources and residential combustion (especially biomass combustion).

Emissions of NMVOC (e.g., olefins, ketones, aldehydes) are the product of incomplete combustion. They are directly influenced by fuel used, usage patterns, technology type and size, vintage, maintenance and operation of the technology. Emission rates may vary by several orders of magnitude for facilities that are poorly operated or improperly maintained, such as might be the case of older units.

The emissions are very low for large-combustion plants. NMVOC emissions tend to decrease with increases in plant size and increasing efficiency of the combustion process.

¹² Non-methane volatile organic compounds: all hydrocarbon compounds, including those where hydrogen atoms are partly, or fully, replaced by other atoms (S,N,O, halogens) excluding those inventoried under the Montreal protocol. They are volatile under ambient air conditions and expressed as mass units as measured.