The emissions calculated using Tier 2 should be reported following the IPCC *Reporting Instructions*:

- **I A 3 a i International aviation (international bunkers)** - note: as far as possible, these emissions are to be excluded from national totals and reported separately.
- **I A 3 a ii Domestic aviation**

TABLE 1-50
EXAMPLES OF AIRCRAFT TYPES AND EMISSION FACTORS FOR LTO CYCLES AS WELL AS FUEL CONSUMPTION PER AIRCRAFT TYPE

	Emission factors (kg/LTO)							Fuel consumption (kg/LTO)
Aircraft type[(a)]	CO_2	CH_4 [(b)]	N_2O[(c)]	NO_X	CO	NMVOC[(b)]	SO_2[(d)]	
A300	5470	1.0	0.2	27.21	34.4	9.3	1.7	1730
A310	4900	0.4	0.2	22.7	19.6	3.4	1.5	1550
A320	2560	0.04	0.1	11.0	5.3	0.4	0.8	810
BAC1-11	2150	6.8	0.1	4.9	67.8	61.6	0.7	680
BAe 146	1800	0.16	0.1	4.2	11.2	1.2	0.6	570
B707*	5880	9.8	0.2	10.8	92.4	87.8	1.9	1860
B727	4455	0.3	0.1	12.6	9.1	3.0	1.4	1410
B727*	3980	0.7	0.1	9.2	24.5	6.3	1.3	1260
B737-200	2905	0.2	0.1	8.0	6.2	2.0	0.9	920
B737*	2750	0.5	0.1	6.7	16.0	4.0	0.9	870
B737-400	2625	0.08	0.1	8.2	12.2	0.6	0.8	830
B747-200	10680	3.6	0.3	53.2	91.0	32.0	3.4	3380
B747*	10145	4.8	0.3	49.2	115	43.6	3.2	3210
B747-400	10710	1.2	0.3	56.5	45.0	10.8	3.4	3390
B757	4110	0.1	0.1	21.6	10.6	0.8	1.3	1300
B767	5405	0.4	0.2	26.7	20.3	3.2	1.7	1710
Caravelle*	2655	0.5	0.1	3.2	16.3	4.1	0.8	840
DC8	5890	5.8	0.2	14.8	65.2	52.2	1.9	1860
DC9	2780	0.8	0.1	7.2	7.3	7.4	0.9	880
DC10	7460	2.1	0.2	41.0	59.3	19.2	2.4	2360
F28	2115	5.5	0.1	5.3	54.8	49.3	0.7	670
F100	2340	0.2	0.1	5.7	13.0	1.2	0.7	740
L1011*	8025	7.3	0.3	29.7	112	65.4	2.5	2540
SAAB 340	945	1.4(E)	0.03(E)	0.3(E)	22.1(E)	12.7(E)	0.3(E)	300(E)
Tupolev 154	6920	8.3	0.2	14.0	116.81	75.9	2.2	2190
Concorde	20290	10.7	0.6	35.2	385	96	6.4	6420
GAjet	2150	0.1	0.1	5.6	8.5	1.2	0.7	680

Source: ICAO (1995).
(a) Except where indicated, values are for world fleet weighted LTO fuel and emissions performance. The average age of aircraft in service is 10-20 years old. Values for aircraft types marked with a * are specific to older types with poorer emissions performance. Aircraft can be equipped with different engines.
(b) Assuming 10% of total VOC emissions in LTO cycles are methane emission (Olivier, 1991).
(c) Estimates based on Tier 1 default values.
(d) The sulphur content of the fuel is assumed to be 0.05%.
(E) indicates that the figure is based on estimations.

TABLE 1-51
EMISSION FACTORS OF NO_x FOR VARIOUS AIRCRAFT AT CRUISE LEVELS

Aircraft	Emission Factor for NO_X (g/kg)		
	ANCAT	NASA	Average
A300	NAV	14.4	NAV
A310	11.5	13.6	12.5
A320	11.7	12.1	11.9
BAC 1-11	7.1	9.3	8.2
BAe 146	6.7	7.7	7.2
B727	8.0	8.7	8.4
B737-200	6.8	7.7	7.3
B737-400	8.3	9.6	9.0
B747-200	16.7	14.2	15.5
B747-400	15.8	13.9	14.9
B757	13.1	12.6	12.9
B767	10.0	12.2	11.1
DC8	12.4	5.6	9.0
DC9	7.6	8.1	7.9
DC10	17.5	13.2	15.4
F28	8.5	8.5	8.5
F100	8.4	6.4	7.4
MD80	8.3	10.6	9.5
TU154	NAV	8.7	NAV
Concorde	19.9	NAV	NAV
GAjet	6.7	NAV	NAV
Source: Gardner et al. (1997) and Baughcum et al. (1996).			

TABLE 1-52
DEFAULT EMISSION FACTORS AND FUEL CONSUMPTION FOR AIRCRAFT
(LTO EMISSION FACTORS ARE GIVEN ON A PER AIRCRAFT BASIS)

	Fuel Consumption	Emission Factors						
Domestic								
		CO_2	CH_4 (a)	N_2O(b)	NO_x	CO	NMVOC(a)	SO_2(c)
LTO average fleet (kg/LTO)	850	2680	0.3	0.1	10.2	8.1	2.6	0.8
LTO old fleet (kg/LTO)	1000	3150	0.4	0.1	9.0	17	3.7	1.0
Cruise (kg/t of fuel)		3150	0	0.1	11	7	0.7	1.0
International								
	Fuel Consumption	**Emission Factors**						
		CO_2	CH_4 (a)	N_2O(b)	NO_x	CO	NMVOC(a)	SO_2(c)
LTO average fleet (kg/LTO)	2500	7900	1.5	0.2	41	50	15	2.5
LTO old fleet (kg/LTO)	2400	7560	7	0.2	23.6	101	66	2.4
Cruise (kg/t of fuel)		3150	0	0.1	17	5	2.7	1.0

Note: The emission factors were calculated as weighted averages for a number of typical aircraft. For domestic traffic, the average fleet is represented by Airbus A320, Boeing 727, Boeing 737--400 and Mc Donald Douglas DC9 and MD80 aircraft. The old fleet is represented by Boeing B737 and McDonald Douglas DC9. For international traffic, the average fleet is represented by Airbus A300, Boeing B767, B747 and McDonald Douglas DC10, whilst the old fleet is represented by the Boeing B707, Boeing B747 and McDonald Douglas DC8. The data for LTO are shown in Table 1-50. Cruise data were taken from Wuebbles et al. (1993). The emission factors for cruise are considered as the best available default factors to date.

(a) For CH_4 and NMVOC it is assumed that the emission factors for LTO cycles be 10% and 90% of total VOC, respectively (Olivier, 1991). Studies indicate that during cruise no methane is emitted (Wiesen et al., 1994).

(b) Estimates based on Tier 1 default values.

(c) Sulphur content of the fuel is assumed to be 0.05% for both LTO and cruise activities.

1.6 Fugitive Emissions: Overview

During all of the stages from the extraction of fossil fuels through to their final use the escape or release of gaseous fuels or volatile components or absorbed gases may occur. The methodologies for the estimation of these emissions (mostly methane) are presented in the sections which follow and are limited to activities conducted within the confines of the energy industries. Emissions from the use of road vehicle fuels are covered under fuel combustion. Emissions from solvents use are estimated within Chapter 3 but emissions arising from the manufacture of solvents within refineries are subsumed within the estimation of emissions from refineries in Section 1.8 Fugitive Emissions from Oil and Natural Gas Activities.

1.7 Fugitive Emissions from Coal Mining and Handling

1.7.1 Overview

This section covers fugitive emissions of greenhouse gases (GHGs) from production, processing, handling and utilisation of coal. Intentional or unintentional releases of gases such as methane in mining are included here, as are emissions from inadvertent combustion of coal in coal mine fires. By far the most important component of this subcategory is methane (CH_4) emissions from the mining and handling of coal. The bulk of this section, therefore, deals with these emissions. Two other fugitive emission sources are discussed briefly at the end of the section. These are burning coal mines and waste piles, which emit CO_2, and SO_2 scrubbing, which is also a source of CO_2. There are very likely other fugitive emissions associated with the coal fuel cycle. If important sources are identified, these will be considered for inclusion in future editions of the *Guidelines*.

1.7.2 CH_4 from Coal Mining and Handling

1.7.2.1 GENERAL METHODOLOGY

The process of coal formation, commonly called coalification, inherently generates methane and other by-products. The formation of coal is a complex physio-chemical process occurring over millions of years. The degree of coalification (defined by the rank of the coal) determines the quantity of methane generated and, once generated, the amount of methane stored in the coal is controlled by the pressure and temperature of the coal seam and by other, less well-defined characteristics of the coal. The methane will remain stored in the coal until the pressure on the coal is reduced, which can occur through the erosion of overlying strata or the process of coal mining. Once the methane has been released, it flows through the coal toward a region of lower pressure (such as a coal mine) and into the atmosphere (Boyer, 1990). Methane emissions from coal mining in 1990 contributed an estimated 23 to 39 Tg of global methane emissions (US EPA, 1993*a*; CIAB, 1992; Airuni and Zeidenvarg, 1992).

The amount of CH_4 generated during coal mining is primarily a function of coal rank and depth, gas content, and mining methods, as well as other factors such as moisture. Coal rank represents the differences in the stages of coal formation and depends on the pressure and temperature history of the coal seam; high coal ranks, such as bituminous coal, contain more CH_4 than low coal ranks, such as lignite. Depth is important because it affects the pressure and temperature of the coal seam, which in turn determines how much CH_4 is generated during coal formation. If two coal seams have the same rank, the deeper seam will hold larger amounts of CH_4 because the pressure is greater at lower depths, all other things being equal. As a result, the methane emission factors for surface-mined coal are assumed to be lower than for underground mining.

In most underground mines, methane is removed by ventilating large quantities of air through the mine and exhausting this air (typically containing a concentration of 1 per cent methane or less) into the atmosphere. In some mines, however, more advanced methane recovery systems may be used to supplement the ventilation systems and ensure mine safety. These recovery systems typically produce a higher concentration product, ranging from 35 to 95 per cent methane. In some countries, some of this recovered methane is used as an energy source, while other countries vent it to the atmosphere. Recent technological innovations are increasing the amount of medium- or high-quality methane that can be recovered during coal mining and the options available to use it. Thus, methane emissions could be reduced from this source in the future.

In surface mines, exposed coal faces and surfaces, as well as areas of coal rubble created by blasting operations, are believed to be the major sources of methane. As in underground mines, however, emissions may come from the overburden (in limited cases where these strata contain gas), which is broken up during the mining process, and underlying strata, which may be fractured and destressed due to removal of the overburden. Because surface-mined coals are generally lower rank and less deeply buried, they do not tend to contain as much methane as underground-mined coals. Thus, emissions per tonne of coal mined are generally much lower for surface mines. Research is underway in the United States and elsewhere to increase the understanding of CH_4 emissions from surface mines (Kirchgessner et al., 1993; USGS, 1993).

A portion of the CH_4 emitted from coal mining comes from post-mining activities such as coal processing, transportation, and use. Coal processing involves the breaking, crushing, and thermal drying of coal, making it acceptable for sale. Methane is released mainly because the increased surface area allows more CH_4 to desorb from the coal. Transportation of the coal contributes to CH_4 emissions, because CH_4 desorbs directly from the coal to the atmosphere while in transit (e.g., in railroad cars). Use of metallurgical coal also emits methane. For instance, in metallurgical coke production, coal is crushed to a particle size of less than 5 mm, vastly increasing the surface area of the coal and allowing more CH_4 to desorb. During the coking process, methane, carbon monoxide, and other volatile gases are released. In modern coke ovens, this gas is typically collected and used as a fuel source, but in older coke ovens, particularly those used in less developed regions, coke gas is vented to the atmosphere (Boyer et al., 1990; coke production is covered in Chapter 3).

Some methane is also released from coal waste piles and abandoned mines. Coal waste piles are comprised of rock and small amounts of coal that are produced during mining along with marketable coal. There are currently no emission measurements for this source. Emissions are believed to be low, however, because much of the methane would likely be emitted in the mine and the waste rock would have a low gas content compared to the coal being mined. Emissions from abandoned mines may come from unsealed shafts and from vents installed to prevent the build-up of methane in mines. There is very little information on the number of abandoned mines, and no data are currently available on emissions from these mines. Most available evidence indicates that methane flow rates decay rapidly once deep mine coal production ceases (Williams and Mitchell, 1992;

Creedy, 1991). In some abandoned mines, however, methane can continue to be released from the surrounding strata for many years. In Belgium, France, and Germany, for example, several abandoned mines are currently being used as a source of methane which is being added to the gas system (Smith and Sloss, 1992; KfA, 1993). Due to the absence of measurement data for both coal waste piles and abandoned mines, no emissions estimates have been developed for these sources.

Review of Previous Methane Emission Estimation Studies

Over the years, a variety of methane emissions estimates have been developed for coal mining, as shown in Table 1-53. As the table shows, the variation in estimates has been quite large, although more recent studies are showing more similar results. Many of the emission studies conducted to date have confronted difficulties in developing estimation methodologies and these have resulted in the widely varying estimates and large uncertainties. These difficulties include:

- **Absence of data on which to base estimates:** Many studies were developed without access to detailed data on methane emissions associated with various components of the coal cycle. For certain sources such as surface mines and post-mining activities, moreover, reliable emissions measurements are still lacking.
- **Use of national data to develop global estimates:** Some studies have relied on data from a single country to estimate global methane emissions from coal mining. This approach can introduce large errors into the estimates, due to the difficulty of generalising from one country's coal characteristics and mining conditions to those of other countries. Mining experience has shown that there are frequently significant differences in methane emission factors within countries, coal basins, and even coal mines for a variety of geological and other reasons.
- **Failure to include all possible emission sources:** Some studies prepared to date have only estimated underground coal mining emissions from ventilation systems and have not included emissions from degasification systems, or post-mining emissions. In addition, many estimates have assumed emissions from surface mines to be negligible and have not included this source. At this point, moreover, there are still potential emission sources, such as abandoned mines, for which emissions cannot be estimated due to the absence of necessary data.
- **Over-reliance on statistical estimation methodologies:** Several studies have estimated global emission factors using statistical models that relate methane emissions to various coal properties. For the most part, these models have proven unreliable when estimates are compared to those developed using more detailed country-specific information. The principal problem with using statistical methodologies is the number of variables that can affect methane emissions. Mining experience has shown that a complete understanding of methane emissions requires detailed examination of coal and geological characteristics and that methane emissions can be highly variable within mines, basins and countries. Collecting comprehensive data and developing statistical models that can reliably predict emissions on a global basis is thus very difficult.

In general, the results of the more recent country-specific and global methane emission studies are likely to be more reliable than previous efforts. For several of the major coal producing countries, for example, detailed data on methane emissions from underground mine ventilation and degasification systems are reported to central institutes and are publicly available. More recent studies have been able to use these data in preparing and validating their estimates of methane emissions from underground mines. Data are still lacking on emissions from surface mines and post-mining activities, thus even the emission estimates from more recent studies should be considered uncertain.

Suggested Emission Estimation Methods

Methane emission estimates should be developed for the three principal sources of methane emissions: underground mines, surface mines, and post-mining activities. To assist in developing these estimates, the IPCC recommends use of a "tiered" approach for estimating emissions. For each source, two or more approaches (or "tiers") are presented for estimating emissions, with the first tier requiring basic and readily available data and higher tiers requiring additional data. Selection among the tiers will depend upon the quality of the data available in the country.

TABLE 1-53
SUMMARY OF EMISSIONS ESTIMATES FROM SELECTED STUDIES

Study Author	Emissions Estimate (Tg)	Year of Estimate	Methodological Issues
Koyama (1963)	20	1960	Hard coal only; no emissions estimates for surface mining or post-mining activities. 1960 coal production data.
Hitchcock & Wechsler (1972)	8 - 28	1967	Post-mining not included; source of emission factors, particularly low end, unspecified. 1967 coal production data.
Seiler (1984)	30	1975	Based on Koyama, with 1975 coal production data.
Crutzen (1987)	34	NA	Source of emission factors unclear. Hard coal only; no emissions estimates for surface mining or post-mining activities.
Okken & Kram (1989)	15 - 45	NA	Source of emission factors unclear. Hard coal only; no emissions estimates for surface mines or post-mining activities.
Zimmermeyer (1989)	24	NA	Only underground mining considered; no emissions estimates for surface mines or post-mining activities.
Seltzer & Zittel (1990)	23	NA	Adjusted Zimmermeyer by: (1) including surface mines; (2) assuming that 15 per cent of underground mining emissions (3.6 Tg) not emitted to the atmosphere due to methane utilisation.
Barns & Edmonds (1990)	25	1986	Assumed mathematical relationship between coal rank and depth and that in-situ methane content was equal to the mining emission factor.
Boyer et al. (1990)	33 - 64	1988	Statistical approach related methane emissions to in situ methane content. Correlation based on US data only. Large uncertainty in application of results for global estimates.
Hargraves (1990)	29	NA	Method based on current methane production rates due to continued coalification.
Airuni and Zeidenvarg (1992)	28	1990	Methodology unspecified.
CIAB (1992)	24	1990	Country specific data used where available for underground mines. Surface and post-mining emissions developed using low emission assumptions. No uncertainty analysis.
US EPA (1993c)	23 - 39	1990	Country specific data used where available for underground mines. Global average emission factors for rest of countries for underground mines and for all surface mining and post-mining emissions.

1.7.2.2 UNDERGROUND MINING

Methane emissions from underground mines should include estimated emissions from ventilation systems and from degasification systems, if any of a country's mines use degasification systems to supplement ventilation. In the approaches outlined below, methods of estimating emissions from both of these sources are presented.

Three possible approaches are suggested by the IPCC, with the choice among them depending upon the availability of data and the degree to which coal mining is considered a significant source of emissions by particular countries. Two of the methods, the "Global" and the "Country or Basin Average" methods are essentially identical in form; only the degree of detail and specificity in choice of emission factor(s) differs. The third, "Mine Specific" method relies on the assembly of methane emission measurements taken at coal mines. In the first two methods, Tiers 1 and 2, ranges of emission factors are given in terms of m^3 CH_4/tonne of coal produced. The structure of the estimation is simply

Emissions (Gg CH_4) = Emission Factor (m^3 CH_4 / tonne)
x tonnes of coal produced
x Conversion Factor ($Gg/10^6m^3$)

A single value from the range of emission factors should be used to prepare the emissions estimate. The relevant coal production figure will be that for the country or the coal basin depending upon the method selected. Factors are given in the table below which permit the conversion of the volume emitted to mass.

For those countries with comparatively large methane emissions from coal mining, the use of more detailed estimation methodologies may be warranted. In countries producing smaller quantities of coal, however, the most simple approach may provide a reasonably accurate first approximation of CH_4 emissions from underground mines.

Tier 1: Global Average Method

The simplest method for estimating methane emissions is to multiply underground coal production by a factor drawn from a range of factors representing global average emissions from underground mining, including both ventilation and degasification system emissions. This method may be selected in cases where total coal production from underground mines is available but more detailed data are not. The Tier 1 Equation is shown below.

EQUATION 1 TIER 1: GLOBAL AVERAGE METHOD – UNDERGROUND MINES
CH_4 Emissions (Gg) = CH_4 Emission Factor (m^3 CH_4/tonne of coal mined)
x Underground Coal Production (Mt)
x Conversion Factor (Gg/10^6 m^3)
Where:
• the Emission Factor should be chosen from the following range
Low CH_4 Emission Factor = 10 m^3/tonne
High CH_4 Emission Factor = 25 m^3/tonne
• Conversion Factor converts the volume of CH_4 to a weight measure and is the density of methane at 20°C and 1 atmosphere, namely:
0.67 Gg / 10^6 m^3

The IPCC recommends revised global average emission factors of 10 to 25 m^3/tonne of coal mined (not including emissions from post-mining activities which should be calculated separately). This range reflects the findings of various country studies, as shown in Table 1-54. As more detailed emissions data are published by various countries, the factors can be further revised, if necessary.

TABLE 1-54
ESTIMATED UNDERGROUND EMISSION FACTORS FOR SELECTED COUNTRIES

Country	Emission Factors (m^3/tonne)	Source
Former Soviet Union	17.8 - 22.2	US EPA, 1993c
United States	11.0 - 15.3	US EPA, 1993a
Germany (East & West)	22.4	Zimmermeyer, 1989
United Kingdom	15.3	BCTSRE, 1992
Poland	6.8 - 12.0	Pilcher et al., 1991
Czechoslovakia	23.9	Bibler et al., 1992
Australia	15.6	Lama, 1992

Tier 2: Country or Basin Specific Method

The suggested Tier 2 approach – called the "Country or Basin Specific Method" – can be used to refine the range of emission factors used for underground mining by incorporating some additional country or basin-specific information. Basically, this method enables a country with limited available data to determine a more appropriate and probably narrower range of emission factors for their underground mines. For many countries, it is expected that this range will fall within the global average emission factor range of 10 to 25 m^3/tonne. The range of possible emission factors is not constrained under the Tier 2 approach, however, and some countries may find that their underground mining emission factors lie outside the global average emission factor range. The calculation procedure is identical to that described in Tier 1.

To implement the Tier 2 approach, national experts must examine measurement data from at least a limited number of underground coal mines in their country or region. Using this data, either statistical analysis or expert judgement should be applied to develop a reasonable range of emission factors for the country or region.[27] Making this estimate will require judgement on the part of the estimator as to the adequacy of the available data and its uncertainty. If sufficient expertise is not available to make such judgements, it is recommended that the Tier 1 approach (the Global Average Method) be used instead.

In some cases, measurement data on emissions from mines may be unavailable but a country will still seek to develop a narrower estimate based on other types of available data. In such cases, a country may seek to develop a simple emissions model based on physical principles or make judgements based on an evaluation of available data. Among the key types of data that should be considered in such a model or evaluation are:

- the gas content of the coal, which contributes to the total amount of methane available for emission during mining;
- the amount of coal within the strata above and below the mined coal seam, which also contributes to the total amount of methane available for emission during mining; and,
- the method of mining, which determines the amount of ground that is disturbed by mining the coal and the extent to which the mining process liberates methane contained in the mined coal seam and in the strata surrounding it.

It should be noted that while the Tier 2 approach can provide some additional information about methane emissions in a particular country or coal basin, the estimates will still be quite uncertain because of the absence of comprehensive and reliable emissions data. This approach should thus be used only in cases where there is a strong need to make an estimate drawn from a narrower range than the Tier 1 (Global Average Method) and not enough data are available to prepare an estimate using the Tier 3 (Mine Specific Method) described in the next section. It should further be noted that an estimate from the narrower range will not necessarily be more accurate than that developed under Tier 1.

In all cases where the Tier 2 approach is used, a detailed discussion of the types of data available and the manner used to determine the refined range of emission factors should be presented, so as to allow for the independent verification of the estimate and ensure comparability with estimates being prepared by other countries.

Tier 3: Mine Specific Method

Because methane is a serious safety hazard in underground mines, many countries have collected data on methane emissions from mine ventilation systems, and some also collect data on methane emissions from mine degasification systems. Where such data are available, the more detailed Tier 3 approach – called the "Mine Specific Method" – should provide the most accurate estimate of methane emissions from underground mines. Since these data have been collected for safety, not environmental reasons, however, it is necessary to ensure that they account for total emissions from coal mines. The key issues that should be considered when using mine safety data, as well as the recommendations of the IPCC for resolving them, are shown in Table 1-55.

[27] If measurement data is available for most or all or a country's underground coal mines, the Tier 3 approach – called the "Mine Specific Method" – should be used to estimate emissions.

Treatment of Methane Utilisation

All of the methods described above, with the possible exception of the Mine Specific Method, assume that all of the methane liberated by mining will be emitted to the atmosphere. In many countries, however, some of the methane recovered by mine degasification systems is used as fuel instead of being emitted. Wherever possible, the emission estimates should be corrected for the amount of methane that is used as fuel, by subtracting this amount from total estimated emissions.

In several countries, data on the disposition of methane recovered by degasification systems (i.e., whether it is used or emitted to the atmosphere) can be obtained from the coal industry or energy ministries. Poland, for example, reports that its mine degasification systems recovered 286 million m^3 of methane in 1989, of which 201 million m^3 was used and the remaining 85 million m^3 was emitted to the atmosphere (Polish Central Mining Institute, 1990). Regardless of the method used to develop the emissions estimates, the Polish emission estimate should be adjusted to reflect the use of methane by subtracting 201 million m^3 from total emissions.

In some countries figures for the quantity of gas recovered from mines may not be available from the mining industry. Nevertheless estimates may be constructed if the users of the gas are known and they are able to give data for their consumption. Consumption may also be inferred if it is known that the gas is used to fuel a particular plant of a known capacity (e.g. if the methane is used to fuel a gas turbine of a known size).

TABLE 1-55
KEY ISSUES FOR CONSIDERATION WHEN USING TIER 3 – MINE SPECIFIC METHOD

ISSUE	DESCRIPTION	RECOMMENDATION
Where and how are ventilation system emissions monitored?	When used to develop overall methane emission estimates, the optimal location for ventilation air monitors is at the point where ventilation air exhausts to the atmosphere.	If ventilation emissions are not monitored at the point of exhaust, emission data should be corrected based on estimated additional methane emissions between the point of measurement and the point of exhaust to the atmosphere.
Are ventilation system emissions monitored and/or reported for all mines?	In some countries, emissions are only reported for "gassy mines".	Estimates should be developed for non-gassy mines as well. Estimates can be prepared using information about the definitions of gassy and non-gassy mines and data on the total number of mines and the coal production at these mines.
Are methane emissions from degasification systems reported?	Some countries collect and report methane emissions from ventilation and degasification systems, while others only report ventilation system emissions. Both emission sources must be included in emissions estimates.	If degasification system emissions are not included, those mines with degasification systems should be identified and estimates prepared on emissions from their degasification systems. Emissions estimates can be based on knowledge about the efficiency of the degasification system in use at the mine or the average efficiency of degasification in the country.

The sources of any adjustments to emissions that are made to reflect the utilisation of methane should be clearly specified, to permit the independent verification of the emissions estimates. In the absence of data, estimated adjustments for the use of methane should not be undertaken.

1.7.2.3 SURFACE MINING

Two possible approaches for estimating methane emissions from surface mining are suggested by the IPCC. For the most part, these approaches resemble those developed for underground mining, but the results will be much more uncertain due to the absence of emissions data. Methane emissions from surface mining are assumed to arise from two sources: the coal mined and the surrounding strata exposed during the mining process. In the Tier 1 approach, (Global Average Method) the separation of these sources is ignored and a single emission factor is used. In the Tier 2 approach (Country or Basin Specific Method), emission factors for each source are required. If emissions measurements are developed in the future, it should be possible to refine these methodologies.

Tier 1: Global Average Method

As for underground mining, the simplest Tier 1 approach for surface mines – called the "Global Average Method" – is to multiply surface coal production by an emission factor selected from a global range, within which most emission factors are believed to lie.

EQUATION 2 TIER 1: GLOBAL AVERAGE METHOD – SURFACE MINES	
CH_4 Emissions (Gg) =	CH_4 Emission Factor (m^3 CH_4/tonne of coal mined)
	x Surface Coal Production (Mt)
	x Conversion Factor ($Gg/10^6$ m^3)

Where:

- the Emission Factor should be chosen from the following range:

  Low CH_4 Emission Factor = 0.3 m^3/tonne

  High CH_4 Emission Factor = 2.0 m^3/tonne

- Conversion Factor converts the volume of CH_4 to a weight measure, and is the density of methane at 20°C and 1 atmosphere, namely:

  0.67 Gg/ 10^6 m^3

In the original IPCC methodology, an average emission factor of 2.5 m^3/tonne was recommended (OECD, 1991), based on the results of Boyer et al. (1990) and including emissions from post-mining operations. Based on more recent analyses and additional studies, a revised emission factor range of 0.3 to 2.0 m^3/tonne is recommended by the IPCC, not including post-mining emissions (US EPA, 1993c; CIAB, 1992; BCTSRE, 1992; CMRC, 1990; Kirchgessner et al., 1993).

Given the lack of information and measurements on methane emissions from surface mines, this range must be considered extremely uncertain, and it should be refined in the future as more data become available.

Tier 2: Country or Basin Specific Method

A second tier estimation of methane emissions – called the "Country or Basin Specific Method" – can be used if additional information is available on *in-situ* methane content and other characteristics of a country's surface-mined coals. This approach enables a country to develop emission factors that better reflect specific conditions in their countries.

Depending on the degree of detail desired, emissions can be estimated for specific coal basins or countries, using the equation below.

EQUATION 3

TIER 2: COUNTRY OR BASIN SPECIFIC METHOD – SURFACE MINES

CH_4 Emissions (Gg) = [*In-Situ* Gas Content (m^3 CH_4/tonne)

x Surface Coal Production (Mt)

x Conversion Factor ($Gg/10^6$ m^3)]

\+ [Assumed Emission Factor for Surrounding Strata (m^3 CH_4/tonne)

x Surface Coal Production (Mt)

x Conversion Factor ($Gg/10^6$ m^3)]

Where:

- *In-Situ* Gas Content and Assumed Emission Factor for Surrounding Strata are described in the text.
- Conversion Factor converts the volume of CH_4 to a weight measure and is the density of methane at 20°C and 1 atmosphere, namely:

$$0.67 \text{ Gg} / 10^6 \text{ m}^3$$

In Equation 3, *In-Situ* Gas Content represents the methane actually contained in the coal being mined, as determined by measuring the gas content of coal samples. Average values for a coal mine, coal basin or country could be developed, depending on the level of detail in the estimate. For surface mines, unlike underground mines, it is frequently assumed that all of the methane contained in the coal is released during mining and that post-mining emissions from surface-mined coals are effectively zero (BTSCRE, 1992; CIAB, 1992; CMRC, 1990). Some countries may choose to modify this assumption based on their specific conditions. Care should be taken, however, to ensure that any emissions assumed to occur during post-mining activities are subsequently estimated.

Assumed Emission Factor for Surrounding Strata represents the possibility that more methane will be emitted during surface mining than is contained in the coal itself because of emissions from the strata below (or in limited cases, above) the coal seam. Some countries have assumed that there are no emissions from surrounding strata associated with surface-mined coals (BTSCRE, 1992; CMRC, 1990). However, if available information indicates that there are gas-bearing strata surrounding the mined coal seam and that these strata are emitting their gas in conjunction with the mining, countries should include these emissions in their estimates.

Emission factors for the surrounding strata can be developed using one of two approaches. Ideally, the assumed emission factor should be based on an evaluation of the gas content of the surrounding strata and verified by measurements. If such data are unavailable, an alternative method of developing an emission factor is to assume that some multiple of the gas content of the mined coal is emitted by the surrounding strata. It should be noted, however, that the alternative approach is highly speculative given the lack of data upon which to base such an assumption.

1.7.2.4 POST-MINING

Like surface mining emissions, there are currently few measurements of methane emissions from post-mining activities. In fact, many past studies have overlooked this emission source, while others have developed only rudimentary estimation methodologies. Two possible approaches for estimating emissions from post-mining activities are recommended by the IPCC.

Tier 1: Global Average Method

For the most simple estimates, a global average emission factor can be multiplied by coal production for underground and surface mining, as shown in the equation below. It is important to distinguish between underground- and surface-mined coals because the gas contents are likely to be very different and hence emissions could vary significantly.

EQUATION 4 TIER 1: GLOBAL AVERAGE METHOD – POST-MINING ACTIVITIES	
Underground CH_4 Emissions (Gg) =	CH_4 Emission Factor (m^3 CH_4/tonne of coal mined)
	x Underground Coal Production (Mt)
	x Conversion Factor (Gg/10^6 m^3)
Surface CH_4 Emissions (Gg) =	CH_4 Emission Factor (m^3 CH_4/tonne of coal mined)
	x Surface Coal Production (Mt)
	x Conversion Factor (Gg/10^6 m^3)

Where:

- Underground CH_4 Emission Factors are in the range of:

  0.9 to 4.0 m^3/tonne

- Surface CH_4 Emission Factors are in the range of:

  0 to 0.2 m^3/tonne

- Conversion Factor converts the volume of CH_4 to a weight measure and is the density of methane at 20°C and 1 atmosphere, namely:

  0.67 Gg/10^6 m^3

Underground-Mined Coals: The IPCC recommends emission factors of 0.9 to 4.0 m^3/tonne for underground-mined coal, based on recent studies (CIAB, 1992; BCTSRE, 1992; US EPA, 1993c).

Surface-Mined Coals: Emission factors of 0 to 0.2 m^3/tonne are recommended by the IPCC for post-mining activities involving surface-mined coal (CIAB, 1992; CMRC, 1990; US EPA, 1993c).

Tier 2: Country or Basin Specific Method

Emissions estimates can be refined if additional data are available on coal characteristics. This method may be preferable if higher tier methods have been used to estimate emissions from underground and surface mines. The equation below summarises the approach for preparing refined emission estimates.

Equation 5 Tier 2: Country or Basin Specific Method – Post-Mining Activities	
a) Underground CH_4 Emissions (Gg) =	*In-Situ* Gas Content (m^3 CH_4/tonne)
	x Underground Coal Production (Mt)
	x Fraction of Gas Released During Post-Mining Activities (%)
	x Conversion Factor ($Gg/10^6$ m^3)
When Necessary:	
b) Surface CH_4 Emissions (Gg) =	*In-Situ* Gas Content (m^3 CH_4/tonne)
	x Surface Coal Production (Mt)
	x Fraction of Gas Released During Post-Mining Activities (%)
	x Conversion Factor ($Gg/10^6$ m^3)
Where:	
• *In-Situ* Gas Content and Fraction of Gas Released During Mining are described in the text	
• Conversion Factor converts the volume of CH_4 to a weight measure and is the density of methane at 20°C and 1 atmosphere, namely: 0.67 $Gg/10^6$ m^3	

In-Situ Gas Content represents the methane actually contained in the coal being mined, as determined by measuring gas contents in coal samples. Average values for a coal mine, coal basin or country could be developed, depending on the level of detail in the estimate.

Fraction of Gas Released During Post-Mining Activities represents the percentage of the in-situ gas content that is assumed to be emitted during post-mining activities. There are three key issues related to the estimation of this fraction:

- For Surface-Mined Coal: In most cases, if the Tier 2 approach is used to estimate methane emissions from surface mines, post-mining emissions from surface-mined coals are assumed to be zero. In these cases, the use of Equation 5(b) is unnecessary and countries should be careful to avoid double counting. **However**, if a country has not assumed that all of the methane contained in surface-mined coal is released during mining, Equation 5(b) should be used to estimate post-mining emissions and the value selected for "Fraction of Gas Released During Post-Mining Activities" should be consistent with the emission factor selected to estimate emissions during surface mining.
- For Underground-Mined Coal: The assumed fractions for underground mining will be based on information about coal permeability, desorption rates, mining methods and other factors. Recent studies have assumed that 25 to 40 per cent of the *in-situ* CH_4 content of underground mined coal is emitted during post-mining activities (US EPA, 1993a; BCTSRE, 1992).
- Fraction of Methane Not Emitted: It is currently assumed that all of the CH_4 contained in mined coal will be emitted to the atmosphere, although it is possible that a fraction could remain in the coal until the point of combustion and be burned instead of emitted. At this time, estimates of the extent to which this may be the

case have not been developed. If countries have such information, however, they could further incorporate this factor into Equation 5.

Total Emissions from Coal Mining Activities

Total methane released as a result of coal mining activities will be the summation of emissions from underground mining (ventilation and degasification systems), surface mining, and post-mining activities. The IPCC recommends that emissions be estimated for each of these categories, in tonnes of CH_4, then aggregated to determine total national methane releases. To the extent that methane that would otherwise have been released to the atmosphere is recovered and used as fuel, the recovered quantity and its use should be reported and the quantity subtracted from the emission total.

Availability and Quality of Activity Data

Data are readily available to develop general emissions estimates using the Tier 1 approach – the Global Average Methods – for underground, surface mining as well as post-mining activities. For these estimates, the only data required are country statistics on underground and surface coal production, which are available from domestic sources, such as energy ministries, or from the OECD/IEA, which publishes Coal Information (OECD/IEA, 1996).

The IPCC recommends that countries involve their coal mining personnel in the development of emissions estimates as much as possible, because of the improved accuracy of emissions estimates prepared with more detailed coal and mining data. The availability and quality of data collected by mining personnel for mine safety purposes should be assessed on a case-by-case basis, however, to ensure that it can be used appropriately for preparing emissions estimates.

The IPCC further recommends that future efforts attempt to better characterise the factors affecting methane emissions from coal mining for those countries and emission sources with limited data, so as to develop more refined emission factors. Specific activities should include:

- Obtaining more data on coal and geological characteristics in selected coal-producing countries;
- Monitoring emissions from surface mines and post-mining activities; and,
- Monitoring emissions from closed or inactive mining operations, and some other potential methane sources, such as mine water.

1.7.3 CO_2 Emissions From Coal Mining and Handling

1.7.3.1 BURNING COAL DEPOSITS AND WASTE PILES

Marland and Rotty (1984) estimated that burning of coal in coal deposits is less than 0.3 per cent of total coal produced and that burning of all coal in waste banks in the United States over a ten year period would represent less than 1 per cent of US coal consumption. Subsequently, they chose to ignore these emissions.

If these sources are estimated, the amount of coal burned in waste piles and coal deposits must be specified along with an emission factor that represents the percentage of coal that is carbon times the percentage of carbon oxidised. We suggest an arbitrary value of 50 per cent of the carbon present in the coal to represent this emission factor; this value would be highly variable from one country to another and one site to another. This assumption of 50 per cent for an emission factor should be evaluated to determine its validity. The formula for calculating these emissions would be:

EQUATION 6	
Emissions from Coal Burning (Gg C) =	Quantity of Coal Burned (10^3 t)
	x Emission Factor
Where:	
• The Emission Factor is:	Percentage of Carbon in Coal
	x Percentage of Carbon Oxidised;
	(and the default value is 50%)

Note that other GHGs such as N_2O, CO, NO_x, etc. are also emitted from combustion of coal wastes.

1.7.3.2 SO_2 SCRUBBING

When SO_2 scrubbing (or flue gas desulphurisation) technology is used in conjunction with combustion of coal, the process, which removes sulphur dioxide from the flue gas, also releases CO_2 from the chemical reactions during the process. This can be considered a fugitive emission resulting from coal use. Typically, calcium carbonate reacts with sulphur oxides in flue gas to produce calcium sulphate and carbon dioxide. Marland and Rotty (1984) suggest that CO_2 emissions from SO_2 scrubbing are small enough to be ignored in global calculations. However, for completeness, some national experts may wish to include this subcategory.

To estimate carbon emissions from SO_2 scrubbing, the approach is derived from Grubb (1989) with slight modifications. In Grubb's approach, carbon emissions would equal the total amount of coal combusted in plants equipped with scrubbers times the fraction of sulphur by weight in the coal, adjusted for the differences in molecular weight between carbon and sulphur (12/32). Since this procedure assumes that all of the sulphur is removed, it should be adjusted by the sulphur removal efficiency of the desulphurisation process (an average removal efficiency of 90 per cent is suggested). The formula for calculating these emissions would be:

EQUATION 7
Emissions from SO_2 Scrubbing (Gg C) = Total Coal Consumption (10^3 t)
x Fraction burned in plants equipped with scrubbers(%)
x Average Sulphur Content of Coal in these plants (%)
x Sulphur Removal Efficiency (default value is 90%)
x 12/32 (i.e., the Carbon/Sulphur Ratio)

Finally, to convert from carbon emissions (in Gg) into CO_2 emissions (in Gg), it is necessary to multiply by 44/12, the molecular weight ratio of CO_2 to C.

1.8 Fugitive Emissions from Oil And Natural Gas Activities

1.8.1 Overview

This section covers fugitive emissions of greenhouse gases (GHGs) from oil and natural gas activities. The category includes all emissions from the production, processing, transport and use of oil and natural gas, and from non-productive combustion. It excludes use of oil and gas or derived fuel products to provide energy for internal use, in energy production processing and transport. The latter are considered fuel combustion and treated in an earlier section of this chapter. Fugitive emissions do include, however, emissions which result from the combustion of natural gas during flaring operations.

By far the most important components of this subcategory are methane emissions from oil and gas production, and from all aspects of natural gas activities. The majority of this section identifies and describes different methane emission sources from oil and natural gas, and presents a default methodology to estimate these emissions on a national level. The basis for estimating methane emissions from oil and gas is, however, weak for most regions at this time. Only a few detailed studies of emissions rates have been performed. Better emissions data that take into account region- and country-specific factors are needed. Information currently available indicates that gas production and transmission in the former USSR and Eastern Europe are by far the most important sources, accounting for perhaps 50 per cent of global CH_4 emissions from oil and natural gas. Because the data are so limited at present, global and regional estimates of CH_4 emissions from this source category should be considered highly uncertain.

The IPCC/OECD/IEA programme has not yet addressed the indirect GHGs (including NMVOCs) in detail. However, the Joint EMEP/CORINAIR method offers both a simplified and a more detailed approach to the estimation of ozone precursors and SO_2. Considerable information has been obtained in other national and international emissions inventory programmes for NMVOCs because of the importance of these gases for local and regional (as well as global) pollution. References to some of the available sources of emission factor data and other information for calculating emissions from this category are provided in the last subsection of this section.

Background

Fugitive emissions of methane from oil and gas activities probably account for about 30 to 60 Tg per year of global methane emissions. Sources of fugitive emissions within oil and gas systems include: releases during normal operation, such as emissions associated with venting and flaring, chronic leaks or discharges from process vents, emissions during maintenance, and emissions during system upsets and accidents.

1.8.2 Oil and Natural Gas Activities

Oil and gas activities are divided into three main parts, for this discussion:

1 **Oil and Gas Production**: Oil and gas are withdrawn from underground formations using on-shore and off-shore wells and are often taken simultaneously from the same geological formation, and then separated. Gathering lines are generally used to bring the crude oil and raw gas streams to one or more collection

point(s) within a production field. Because methane is the major component of natural gas, leaks or venting from these systems result in methane emissions. Oil and/or gas are produced in approximately 186 countries world-wide.

2 **Crude Oil Transportation and Refining**: Crude oil is transported by pipelines and tankers to refineries where it is stored in tanks for a period of time. Methane is present, in varying degrees, in crude oil, and leaks or venting of vapours during transport and storage result in methane emissions, particularly from crude oil tankering.

Refineries process crude oil into a variety of hydrocarbon products such as gasoline and kerosene. During the refining process, dissolved gases are separated some of which may be leaked or vented during processing. Refinery outputs, referred to as "refined products," generally contain negligible amounts of methane. Consequently, methane emissions are not estimated for transporting and distributing refined products. Refineries are operated in 102 countries.

3 **Natural Gas Processing, Transportation, and Distribution**: Natural gas is processed to recover heavier hydrocarbons, such as ethane, propane and butane, and to prepare the "dried" gas for transport to consumers. Most gas is transported through transmission and distribution pipelines. A small amount of gas is shipped by tanker as liquefied natural gas (LNG). Because for the time being only a small portion of gas is transported as LNG, emissions from LNG facilities are not included in default emission methods.

The following are the main processing, transportation, and distribution activities:

- Gas processing plant: Natural gas is usually processed in gas plants to produce products with specific characteristics. Depending on the composition of the unprocessed gas, a variety of processes may be used to remove most of the heavier hydrocarbons, or condensate, from the gas. The processed, marketable, gas is then injected into the natural gas transmission system and the heavier hydrocarbons are marketed separately. Unintentional leaks of methane occur during natural gas processing.

- Transmission pipelines: Transmission facilities are high pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to distribution centres, or large volume customers. Although transmission lines are usually buried, a variety of above-ground facilities support the overall system including metering stations, maintenance facilities, and compressor stations located along the pipeline routes. These activities use gas from the pipeline as fuel and may emit methane.

- Distribution systems: Distribution pipelines are extensive networks of generally small diameter, low pressure pipelines. Gas enters distribution networks from transmission systems at "gate stations" where the pressure is reduced for distribution within cities or towns. As with transmission pipelines emissions from leaks or supporting facilities may take place.

1.8.3 Sources of Methane Emissions from Oil and Natural Gas Activities

Emissions from oil and gas activities can be categorised into: (1) emissions during normal operations; (2) maintenance; and (3) system upsets and accidents. Typically the majority of emissions are from normal operations.