1 **Normal Operations:** . Emissions from normal operations can be divided into two main source categories: (1) venting and flaring and (2) discharges from process vents, chronic leaks, etc.

Venting and Flaring - Venting and flaring refers to the disposal of gas that cannot be contained or otherwise handled. Such venting and flaring activities are associated with combined oil and gas production and take place in production areas where gas pipeline infrastructure is incomplete and the natural gas is not injected into reservoirs (emissions from process vents are not included here - see below).

Venting activities release methane because the vented gas typically has a high methane content. If the excess gas is burned in flares the emissions of methane will depend on how efficient the burning processes are. Generally the combustion efficiency for flare sources are assumed to be between 95 and 100 per cent. However a new study based upon measurements carried out by Norwegian Oil Industry Association - OLF (1993) indicates very small amounts of unburned methane from flares, less than 0.1 per cent of the gas flared. To estimate the methane emissions from venting and flaring activities satisfactorily it is required to know the flare efficiency rates and the division between the quantity of gas vented and gas flared.

The *combined* quantity of gas vented and flared is reported by countries that produce oil and gas (Barns and Edmonds, 1990). A few countries also are able to report separately gas vented and gas flared. The reliability of the data is questionable in many cases because vented and flared amounts are not normally metered but inferred from the difference between total production and disposals.

Discharges from Process Vents, Chronic Leaks etc. - These include:

- Emissions from pneumatic devices (gas-operated controls such as valves and actuators) depend on the size, type, age of the devices, the frequency of their operation and the quality of their maintenance.
- Leaks from system components are unintentional and usually continuous releases resulting from the failure of a seal or the development of a flaw, crack or hole in a component designed to contain or convey oil or gas. Connections, valves, flanges, instruments, and compressor shafts can develop leaks from flawed or worn seals, while pipelines and storage tanks can develop leaks from cracks or from corrosion.
- Emissions from process vents, such as vents on glycol dehydrators and vents on crude oil tankers and storage tanks resulting from normal operation of the facilities. However such process vents are minor methane sources in most gas production facilities.
- Emissions from starting and stopping reciprocating engines and turbines.
- Emissions during drilling activities, e.g., gas migration from reservoirs through wells.

2 **Maintenance:** Includes regular and periodic activities performed in the operation of the facility. These activities may be conducted frequently, such as launching and receiving scrapers (“pigs”) in a pipeline, or infrequently, such as evacuation of pipes ("blowdown") for periodic testing. In each case, the required procedures release gas from the affected equipment. Releases also occur during maintenance of wells ("well workovers") and during replacement or maintenance of fittings.

3 **System Upsets and Accidents:** System upsets are unplanned events in the system, the most common of which is a sudden pressure surge resulting from the failure of a pressure regulator. The potential for unplanned pressure surges is

considered during facility design, and facilities are provided with pressure relief systems to protect the equipment from damage due to the increased pressure. Relief systems vary in design. In some cases, gases released through relief valves may be collected and transported to a flare for combustion or re-compressed and re-injected into the system. In these cases, methane emissions associated with pressure relief events will be small. In older facilities, relief systems may vent gases directly into the atmosphere or may send gases to flare systems where complete combustion may not be achieved.

The frequency of system upsets varies with the facility design and operating practices. In particular, facilities operating well below capacity are less likely to experience system upsets and resulting emissions. Emissions associated with accidents are also included under the category of upsets. Occasionally, gas transmission and distribution pipelines are accidentally ruptured by construction equipment or other activities.

Table 1-56 lists the most important sources of emissions within each segment of the oil and gas industry. Based on available information, the sources listed as "major" account for the majority of emissions from each segment. Because data are limited and, because there is considerable diversity among oil and gas systems throughout the world, other possible sources are listed which may, in some cases, be important contributors to emissions.

TABLE 1-56
METHANE EMISSIONS FROM OIL AND NATURAL GAS ACTIVITIES

Segment	Major Emission Sources	Other Possible Emission Sources
Oil and Gas Production Oil and Gas Wells Gathering lines Treatment facilities	Venting Normal operations: fugitive emissions; deliberate releases from pneumatic devices and process vents	Flaring, maintenance, system upsets and accidents
Crude oil transportation and Refining Pipelines Tankers Storage tanks Refineries	Normal operations: fugitive emissions; deliberate releases from process vents at refineries, during loading and unloading of tankers and storage tanks	Flaring, maintenance, system upsets and accidents
Natural Gas Processing, Transportation, and Distribution Gas Plants Underground storage reservoirs Transmission Pipelines Distribution Pipelines	Normal operations: fugitive emissions; deliberate releases from pneumatic devices and process vents	Flaring, maintenance, system upsets and accidents

1.8.4 Available Emissions Data

Only very limited data are available that describe methane emissions from natural gas and oil activities. Estimating the types of emissions defined above is complicated by the fact that emissions rates from similar activities in various regions and countries are influenced by differences in the industry's supporting infrastructure, operating and maintenance practices, and level of technology used. Because natural gas and oil activities are complex, it is not easy to define simple relationships between emissions and gross descriptors of the activities undertaken.

The available published data were reviewed to identify emissions estimates that include: a detailed consideration of the physical attributes of oil and gas systems; the operation and maintenance characteristics of key facilities; and country- or region-specific factors that may influence emission rates. The following data were identified:

- **Surveys:** Several studies have surveyed system operators to estimate emissions as a fraction of production or throughput. These studies include Alphatania (1989), AGA (1989), and INGAA (1989). While these studies provide a basis for identifying the activities that operators believe are likely to be major sources of emissions, they are not based on detailed assessments of emission rates and therefore do not provide a quantitative basis for making estimates of methane emissions from oil and natural gas activities.

- **Estimates Based on "Reported Unaccounted For Gas":** Several studies, such as Hitchcock and Wechsler (1972), Abrahamson (1989) and Cicerone and Oremland (1988), have assumed that emissions can be approximated by reported amounts of "unaccounted for" gas. Unaccounted for gas is defined as the difference between gas production and gas consumption on an annual basis. Like estimates of venting and flaring, unaccounted for gas often is used as an accounting convenience to balance company or national production and consumption estimates.

  The use of unaccounted for gas estimates as estimates of emissions is questionable because factors other than emissions account for the majority of the gas listed as unaccounted for. These include: meter inaccuracies, use of gas within the system itself, theft of gas (PG&E, 1990), variations in temperature and pressure and differences in billing cycles and accounting procedures between companies receiving and delivering the gas (INGAA, 1989). Furthermore, because known releases of gas are not reflected in unaccounted for gas estimates, such as emissions from compressor exhaust, the unaccounted for gas estimates cannot unambiguously be considered an upper or lower bound on emissions.

- **Engineering Studies and Measurements:** A small number of studies are based on detailed engineering and/or field measurement analyses. Several engineering analyses have considered the manner in which actual or model facilities are built and operated, and extrapolate facility emissions to a system-wide basis. Several measurement studies have measured emissions from operating facilities or identified actual leaks and extrapolated these measurements to estimate system-wide emissions. In general, data from engineering studies and measurements are the preferred basis for emission estimates. However, only a few of these types of studies have been performed, thereby limiting the ability to estimate emissions nationally, regionally and globally from oil and gas systems. Table 1-57 lists the studies identified and the information they contain. The methane emissions estimates from the studies in the table have been converted to common units of kilograms of emissions per petajoule of energy (kg/PJ). A total of five studies are listed, with emissions estimates for parts of North America (US EPA, 1992), Eastern Europe (Rabchuk et al., 1991), and Western Europe (Schneider-Fresenius et al., 1989, Norwegian SPCA, 1992b and Norwegian Oil Industry Association OLF, 1993). Additionally, Barns and Edmonds (1990) present estimates based on a global assessment. Further studies are needed to improve the basis for making emissions estimates.

TABLE 1-57
SUMMARY OF METHANE EMISSION FACTORS

Data source	Study methodology	Emission factors	Applicability
US EPA (1992)	Compilation of estimates from:	**Oil and Gas Production:**	
All emissions have been scaled down to 1988 energy consumption or production levels	• detailed engineering analyses • field measurement studies	290 - 4 670 kg/PJ of oil produced	Emissions from non-gas producing oil wells including fugitive emissions and maintenance emissions in the USA
		39 590 - 104 220 kg/PJ of gas produced	Emissions from gas production, including fugitive emissions, dehydrator venting, bleeding from pneumatic devices, maintenance, and systems upsets in the USA
		2 870 - 13 920 kg/PJ of total oil and gas produced	Venting and flaring emissions from oil and gas production and fugitive emissions from gas-producing oil wells in the USA
		Crude Oil Transportation and Refining:	
		110 - 1 666 kg/PJ of oil refined	Emissions from oil refining and related oil storage tanks in the USA
		Natural Gas Processing, Transmission and Distribution:	
		59 660 - 116 610 kg/PJ of gas consumed	Emissions from gas processing, transmission and distribution including fugitive emissions, dehydrator venting, bleeding from pneumatic devices, maintenance, and system upsets in the USA
Rabchuk et al. (1991)	Compilation of estimates from:	**Oil and Gas Production:**	
	• previous measurement studies • official data for 1989	218 000 - 567 600 kg/PJ of gas produced	Emissions from leakages at gas wells including routine equipment venting in the former USSR
		Natural Gas Processing, Transmission and Distribution:	
		340 000 - 715 800 kg/PJ of gas consumed	Emissions from leakages at underground storage facilities, compressor stations, linear part of main pipelines and distribution networks in the former USSR
Schneider-Fresenius et al. (1989)	Compilation of results from:	**Oil and Gas Production:**	
	• Batelle study's 1988 literature survey	14 800 - 270 00 kg/PJ of gas produced	Emissions from gas production and treatment facilities in Germany
		Natural Gas Processing, Transmission and Distribution:	
		58 000 - 111 000 kg/PJ of gas consumed	Emissions from transportation, distribution and storage of gas in Germany

TABLE 1-57 (CONTINUED) SUMMARY OF METHANE EMISSION FACTORS			
Data source	**Study Methodology**	**Emission Factors**	**Applicability**
Barns and Edmonds (1990)	Compilation of:	**Oil and Gas Production:**	
	official reports and projections on international emissions	96 000 kg/PJ of natural gas production	Emissions from gas production and separation facilities in the world
		6 300 - 1 019 000 kg/PJ of gas production	Emissions from venting and flaring activity by region of the world
Norwegian SPCA (1992b)	Summary of:	**Oil and Gas Production:**	
	emissions estimates for 1989 based on:	12 800 kg/PJ of gas produced	Emissions from cold vents and fugitive emissions
	information and measurements collected from oil companies	3 200 kg/PJ of gas produced	Flare and gas turbines
	and industry associations	200 kg/PJ of gas produced	Pre-production emissions (well testing)
		Crude oil transportation:	
		2 500 kg/PJ oil tankered	Emissions from offshore loading of crude oil
		Natural gas processing:	
		1 800 kg/PJ of gas processed	Emissions from one Norwegian gas processing terminal
Norwegian Oil Industry Association (OLF), 1993	Summary of emission estimates based on:	**Oil and Gas Production:**	
	information and measurements collected from oil associations	3 000 - 7 500 kg/PJ of gas produced	Emissions from cold vents and fugitive emissions
		100 - 400 kg/PJ of gas produced	Pre-production emissions

1.8.5 Recent Revisions to Emission Factors

The above methodology and emission factors are based on the report of an expert group convened to advise the IPCC/OECD/IEA programme on methods and data in this specific area (Ebert, et al., 1993). Since that group delivered its report in mid-1993, a more recent analysis (US EPA, 1994b) has provided a somewhat different interpretation of some emission factors. While this very detailed analysis endorses the basic tiered methodology included in this *Manual*, the emission factors it derives differ from those presented here. This evaluation was based on essentially the same set of measurement data as cited in this *Manual*, but draws different results from the limited available data. The results of the recent US EPA analysis are summarised in Table 1-58. The most significant differences are in natural gas processing, transportation and distribution, where a more detailed set of emission factor ranges are recommended for non-OECD countries, some which are based on production of natural gas and some which are based on consumption of natural gas (which is the case for all of the factors provided above). Where emission factors are provided for more than one subcategory, they are intended to be additive, and would result in a higher total emissions estimates. Other differences in this US EPA analysis are that venting and flaring emissions for Western Europe are based on oil rather than gas production, and there are minor revisions to some factors for fugitive and other emissions from gas production.

These differences are significant, even given the overall uncertainty in this category, and should be considered carefully by national experts in regions where emissions from this source category are significant. It is hoped that the differences can be resolved or explained in more detail in a subsequent version of these *Guidelines*.

TABLE 1-58
REVISED REGIONAL EMISSION FACTORS FOR METHANE FROM OIL AND GAS ACTIVITIES (kg/PJ)

Source Type	Basis	Western Europe	US & Canada	Former USSR, Central & Eastern Europe	Other Oil Exporting Countries	Rest of the World
OIL & GAS PRODUCTION						
Fugitive and Other Maintenance Emissions from Oil Production	Oil Produced	300 - 5 000	300 - 5 000	300 - 5 000	300 - 5 000	300 - 5 000
Fugitive and Other Maintenance Emissions from Gas Production	Gas Produced	15 000 - 27 000	46 000 - 84 000	140 000 - 314 000	46 000 - 96 000	46 000 - 96 000
Venting & Flaring from Oil and Gas Production	Oil & Gas Produced[(a)]	-	3 000 - 14 000	-	-	-
	Oil Produced	1 000 - 3 000	-	-	-	-
	Gas Produced	-	-	6 000 - 30 000	758 000 - 1 046 000	175 000 - 209 000
CRUDE OIL TRANSPORTATION, STORAGE AND REFINING						
Transportation	Oil Tankered	745	745	745	745	745
Refining	Oil Refined	90 - 1 400	90 - 1 400	90 - 1 400	90 - 1 400	90 - 1 400
Storage Tanks	Oil Refined	20 - 250	20 - 250	20 - 250	20 - 250	20 - 250
NATURAL GAS PROCESSING, TRANSPORT AND DISTRIBUTION						
Emissions from Processing, Distribution and Transmission	Gas Produced	-	-	288 000 - 628 000	288 000 (high)[(b)]	288 000 (high)[(b)]
	Gas Consumed	72 000 - 133 000	57 000 - 118 000	-	118 000 (low)[(c)]	118 000 (low)[(c)]
Leakage at industrial plants and power stations	Non-residential Gas Consumed[(d)]	-	-	175 000 - 384 000	0 - 175 000	0 - 175 000
Leakage in the residential and commercial sectors	Residential Gas Consumed[(e)]	-	-	87 000 - 192 000	0 - 87 000	0 - 87 000

(a) In the US and Canada, the emissions are based on total production of both oil and gas produced.

(b) The emission factor of 288 000 kg/PJ of gas produced is used only for the high emissions estimate.

(c) The emission factor of 118 000 kg/PJ of gas consumed is used only for the low emissions estimate.

(d) Gas consumption by utilities and industries.

(e) Gas consumption by the residential and commercial sectors.

Source: US EPA (1994b).

1.8.6 Methodologies For Estimating Methane Emissions

A three-tiered approach is presented for estimating methane emissions from oil and gas activities. The specific tiers are listed below in the order of increasing sophistication, data requirements, and accuracy:

- Tier 1 - Production-Based Average Emission Factors Approach,
- Tier 2 - Mass Balance Approach, and
- Tier 3 - Rigorous Source-Specific Approach.

Countries should select the approach or combination of approaches that is most suited to their circumstances. Some important considerations may include the relative contribution of oil and natural gas to total methane emissions for the country, the available information and resources, and the complexity of the local oil and gas industry.

Regardless of the method that is used, the results must be aggregated back to a Tier 1 format to provide a consistent basis for comparison.

Note that methane emissions from combustion plant and incomplete combustion in flaring processes in the non-oil and gas industry are excluded. They are accounted for separately in the section on methane emissions from combustion and industry.

Tier 1 - Production-Based Average Emission Factors Approach

This is the simplest approach for estimating CH_4 emission from oil and gas activities, and is the only one that does not require any direct interaction with the oil and gas industry and associated regulatory agencies. Accordingly, it is the least reliable of the methods.

The required activity data may be easily referenced from published documents of the IEA or the United Nations Statistical Division, and the necessary emission factors are provided in this document. The Tier 1 Approach can be used as a starting point for any country, and may be all that is needed where the emissions from a country's oil and gas industry are comparatively small and/or where data or resources are not available to pursue a more rigorous approach.

Production Base: To estimate emissions, the following steps are recommended as a default estimation procedure:

1 Global oil and gas systems have been divided into regions with relatively homogeneous oil and gas system characteristics. Each country should decide which system characterisation best fits its own oil and gas system(s).

2 For each region, representative emission factors for each activity within each segment have been selected with the objective of taking into account the various system designs and operating practices found in each region.

3 For each country, country-specific activity levels must be obtained and multiplied by the appropriate emission factor. Emission factors for countries should be selected from those corresponding to the appropriate region.

As more data become available for oil and gas producing activities within different countries, the default methodology described above (including activity data and emission factors) should be refined. Each step is discussed below in more detail.

Regional Definitions: Regions have been defined considering the limitations in data on emission factors and activity levels, but also recognising the key differences in oil and gas systems that are found globally. The following five regions are recommended at this time:

- **USA and Canada:** The United States is a large producer and importer of oil and is a large producer of gas. Detailed emissions estimates are available for the United States.
- **Former USSR and Eastern Europe:** Indications are that emission rates from this region are much higher than emission rates from other regions, in particular for the gas system. This region includes the former USSR (which is by far the largest oil and gas producer in the region), Albania, Bulgaria, Czech & Slovak Republics, Hungary, Poland, Romania, and the former Yugoslavia.
- **Western Europe:** This region is a net importer of oil and gas, and mainly produces oil and gas off shore. This region includes: Austria, Belgium, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.
- **Other Oil Exporting Countries:** This region includes the world's other major oil producing countries: the 11 OPEC members (Algeria, Libya, Nigeria, Venezuela, Indonesia, Iran, Iraq, Kuwait, Qatar, Saudi Arabia and the United Arab Emirates), Gabon, Ecuador and Mexico. Generally, these countries produce large quantities of oil and have limited markets for gas.
- **Rest of the World:** This region includes the remaining countries of Asia, Africa, Middle East, Oceania and Latin America.

In defining these regions, countries with relatively similar oil and gas systems were aggregated. Additional investigation would likely improve the definition of the regions.

Emission Factors: As discussed above, the basis for selecting emission factors is weak because very few detailed studies of emissions have been performed. Using the information summarised in Table 1-57, emission factors should be selected by industry segment and emission type for each of the regions. In some cases data from the United States were used when region-specific information was not available.

Tables 1-60 to 1-64 offer emission factors for each region. Emission factors from US EPA (1992) were used for the United States. Key emission factors for Eastern Europe and the Former USSR were taken from Rabchuk et al. (1990) and Barns and Edmonds (1990). Estimates were used for emission factors for venting and flaring for the several regions, including Eastern Europe.

Studies by Schneider-Fresenius et al. (1989) and Norwegian SPCA (1992b) were adopted as representative of emission factors for Western European gas production, venting and flaring. No region-specific data were available for the Other Oil Exporting countries and the Rest of the World. Emission factors in these regions are expected to fall between the relatively low rates found in North America and Western Europe and the relatively high rates found in Eastern Europe. Consequently, a range of emission factors is suggested for these regions unless more information can be obtained.

Activity Levels: Data on the quantity of oil and gas produced, refined, and consumed can be obtained from the IEA or the UN Statistical Division. Sources are described in Section 1.2.1 Data Sources. Data on oil refining capacity can be used to approximate oil refined. Data on oil tankered were not available by region. It is important for national experts to ensure that production figures used in calculation of apparent consumption for CO_2 emissions estimates (described in the Tier 1 method for CO_2) are consistent with those used in this section.

Tier 2 - Mass Balance Approach

The Mass Balance Approach is only recommended for oil system releases of CH_4, and should not be used for releases from natural gas activities. No Tier 2 method exists for natural gas activities. This is a priority for future work. The Mass Balance Approach employs standard, generally easy-to-obtain, oil and gas data (i.e., production volumes, gas-to-oil ratios (GORs), and gas compositions) to estimate the maximum amount of methane that could be emitted to the atmosphere by different sectors of the oil and gas industry. These amounts are then scaled to reflect actual emissions by applying appropriate emission factors. The minimum emission factors account for the amount of gas that is disposed of by control devices, consumed by combustion equipment, conserved, or reinjected. Leak emission factors account for the amounts lost through leaks from these control/utilisation systems.

The basic procedures for performing the mass balance calculations for each oil and gas activity are set out below. Total CH_4 emissions is the sum of emissions for each of these activities. Default data and factors are provided where possible.

Oil Production: Emissions from oil production may be estimated using the relation,

$$E_{Oil\text{-}P} = Q_{Oil-P} \times GOR \times Y_{CH_4} \times K_{Oil-P} \times D_{GOR} \times 10^{-12}$$

where

$E_{Oil\text{-}P}$ = methane emissions from oil production (Tg/year)

$Q_{Oil\text{-}P}$ = oil produced (m^3/year)

GOR = gas to oil ratio; defines the amount of gas produced (in volume) per unit of oil produced (in volume). (m^3/m^3, or dimensionless).

Y_{CH_4} = methane Fraction; the volume of gas dissolved in the oil that is methane, on a volume basis, for example, 0.1 m^3 of methane per 1.0 m^3 of gas. (may be considered dimensionless)

$K_{Oil\text{-}P}$ = emission factor for oil production, see below (dimensionless)

D_{GOR} = density of methane at the temperature and pressure at which the GOR is estimated, (g/m^3). The relevant temperature and pressure may vary, depending on the values used to calculate the GOR. For example, at 0°C and a pressure of 1 atmosphere, the density of methane is 715.4 g/m^3, and at 20°C, and a pressure of 1 atmosphere, the density of methane is 666.6 g/m^3.

The first two terms ($Q_{Oil\text{-}P}$ and GOR) estimate the total amount of gas that is withdrawn from the ground while the oil is produced. The term Y_{CH_4} converts the total gas quantity into the quantity of methane (still on a volume basis). The emission factor ($K_{Oil\text{-}P}$) is the fraction of the total gas withdrawn that is emitted. At most, $K_{Oil\text{-}P}$ = 1. To put the emissions estimate on a mass basis, D_{GOR} is used to estimate grams, and the conversion to teragrams follows.