EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS AND GEOTHERMAL ENERGY

SNAP CODE : **050101**
050102
050103

SOURCE ACTIVITY TITLE : **Extraction and First Treatment of Solid Fossil Fuels**
Open Cast Mining
Underground Mining
Storage of Solid Fuel

NOSE CODE : **106.01.01**
106.01.02
106.01.03

1 ACTIVITIES INCLUDED

This section covers only coal, not peat or other solid fuels. Subsequent treatment of coal, such as fuel conversion, coking, gasification or liquefaction are not treated in this chapter, but are included in related chapters of the guidebook.

2 CONTRIBUTION TO TOTAL EMISSIONS

The extraction and first treatment of solid fuels results in emissions of methane from mining operations. This sector was estimated to be responsible for 22% of national emissions of methane in the UK in 1991 (Gilham 1994). Limited reliable data is available for the other pollutants.

3 GENERAL

3.1 Description

Coalfields contain a proportion of highly volatile material which is released during the working, extraction and storage of coal. The volatile material is known as firedamp, made up primarily of methane, although other compounds are also present in minor amounts.

The release of firedamp often results in an emission to air as it not always economical to contain the gas, for flaring or use as a fuel.

During coal extraction, the following processes connected with methane emission can be identified:

a) developing access to the coal deposit and its preparation for extraction;
b) coal extraction and transport on the surface;
c) coal processing, disposal, transport and crushing before final use;
d) deposit de-methaning before, during and after its excavation;
e) disposal of spoils from the coal extraction system.

Air containing methane is emitted usually to the atmosphere because its use as fuel or for combustion purposes is not economically viable, mainly due to the high dilution.

3.2 Definitions

Fire-damp - inflammable gas released during the working of coal mines. In general, methane is considered a safety hazard.

3.3 Techniques

Two types of mining operations are considered in this chapter - deep mines and open cast mines. In addition, it is important to note that coal varies considerably from one field to another, depending on its age and geological location. The proportion of fire-damp associated with the different types of mining and the different types of coal have shown considerable variation. Attempts to model the relationship between the proportion of fire-damp and factors such as depth of coal seam, nature of coal and local geology have shown some correlations although the associated uncertainty is very large.

Once coal is extracted, it may be stored, transported internally or exported, or a combination of all three. Associated gaseous emissions continue to occur and it is thought that these will be related to the coal type, the size of the coal pieces, the mechanical disturbance during handling etc.

3.4 Emissions/Controls

In technological processes performed in underground workings, methane is released which, unless taken in by the de-methaning systems, is discharged to the atmosphere by the ventilation systems of the mines. The ventilation systems are the primary and main methane emission source from coal mines. Emission from the ventilation systems is described as ventilation emission. Methane, in this case called “residual gas”, is also contained in the coal extracted to the surface and released during the extraction processes. Emission related to these processes is called emission from extraction processes. This emission constitutes the second methane emission source in coal mining.

Some methane is also contained in the bed rock extracted to the surface with coal and gets released during bed rock disposal. This is the third source of methane emission. The fourth source is the de-methaning systems. The methane collected by these systems is not totally utilised or combusted in flames and some or all of the volume is emitted as “whistler” to the atmosphere.

In open casting coal extraction, there are two main sources of ventilation emission:
- emission from the extracted coal;
- emission from the deposits coating the working.

The primary emission of fire-damp is believed to occur during the extraction of deep mine coal. Open cast mining, since it involves the extraction of coal seams close to the surface, and the handling and storage of coal, are not considered to be as important.

In many cases, firedamp is actively removed from the coalfield, by various methods, normally described collectively as methane drainage. This is primarily for reasons of safety. As an example, in the UK, in 1988, 16% of the fire-damp released by deep mining was vented from methane drainage systems, 11% was captured and used as fuel, 61% was emitted with ventilation air and about 12% was removed in the mined coal.

Data from Russia (Tsibulski 1995) indicates that the balance of methane emissions from coal seams and enclosing rocks is distributed as follows:

60%	emitted to atmosphere from mines together with ventilation air
12%	captured in mines and if not utilised then also emitted
15%	emitted to atmosphere from coal extracted to the surface
13%	remains in the seam and surrounding rock

Firedamp may be removed before the mining of a coal seam (pre-drainage) or as a consequence of mining (post-drainage). The latter approach is likely to be the most common.

3.4.1 Post-drainage Technologies

Cross-measures Methane Drainage

Boreholes are drilled at an angle above, and sometimes below, the mined out area, which collapses as the coal is removed. The boreholes are drilled close to the coalface and linked to a common pipe range. Suction is applied to the pipe range to draw the gas to a discharge point. Depending on circumstances and geology, 35% to 75% of the total gas released in an underground district can be captured at purities ranging from 30% to 70%. Higher purity gas is generally not available.

Surface ‘Gob’ Well Post-drainage

This technology is well established in the US. Gas is drained via surface boreholes from the de-stressed zone above a caving ‘long-wall’ face. The gas produced is generally of high purity. The principle disadvantage is high drilling costs and surface environmental planning restrictions.

Other methods of post drainage include Super-Adjacent Drainage Heading (Sewer Road) and Super Adjacent Guided Long-hole. Both methods involve driving long boreholes or roadways adjacent to the worked coalface (typically with 30m to 40m). The applicability is very much dependent on local geology.

3.4.2 Pre-drainage Technologies

In-seam Boreholes

This requires drilling boreholes parallel to the undisturbed coalface. The success of this technique depends on the permeability of the coal and the gas pressure. The higher the permeability and gas pressure, the greater the efficiency.

Hydrofracced Surface Boreholes

This technique involves hydraulically fracturing a sequence of productive horizons, injecting sand into the fractures and connecting the fractures to a well head assembly. Gas and other fluids occupy the sand-filled fractures and enter the well head assembly without encountering excessive resistance. The technique has been applied in the US, but is also very dependent on geology.

3.4.3 Extracting Pollutants from the Ventilation Air

Besides active drainage of gas, removal also occurs as a result of the ventilation of the mine. Using the ventilation air as feed air for boilers or engines may control organic compounds associated with ventilation air. Liquefaction of gases, catalytic or biological oxidation are generally inappropriate for low concentrations of organic compounds found in ventilation air.

3.4.4 Utilisation of Firedamp

Reducing Emissions by Flaring

Flaring is not a common method for controlling firedamp, since to practice this safely is often prohibitively expensive.

Reducing Emissions by Using Gas as a Fuel

This is not a new concept. Since recovering combustible material from ventilation air is expensive, the technique applies primarily to actively drained firedamp. Whether or not firedamp is used as a fuel depends primarily on financial considerations, particularly if ensuring a continuous supply requires backup fuels such as Liquid Petroleum Gas, and if competitor fuels are readily available.

4 SIMPLER METHODOLOGY

The simpler methodology involves the application of a general emission factor to an appropriate activity statistic for each of three categories:

- underground coal mine
- open coal mine
- post mining treatment and storage.

5 DETAILED METHODOLOGY

This requires data to be collected for each major coalfield. Specific emission factors for each field are obtained primarily by measurement or inferred from related data from similar fields. The field specific emission factors are used to derive field specific emissions.

Within the detailed methodology data on emissions from individual mines needs to be obtained. Emission determination can be performed using specific emission factors and data on the extraction volume, emission measurements, data on methane intake in the degassing units and the volume of the “whistler” from the de-methaning systems.

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology the relevant activity statistic is total mass of coal produced by underground mining and the total tonnage of coal produced by opencast mining.

For the more detailed approach, the activity statistic is the tonnage of coal produced from regions or coalfields where each available emission factor can be applied.

7 POINT SOURCE CRITERIA

The underground coalmines can be considered as point sources if the relevant site-specific data are available. It can be necessary in the case the modelling of pollutants dispersion in local or regional scale.

The opencast mining should be considered as area sources due to large area covered by coal extraction activities.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

The IPCC Guidelines for National Greenhouse Gas Inventories give a comprehensive review of emission factors derived from measurements and modelling studies.

The default Emission Factors, to be used when no better data is available, are as follows:

Mining Activities	
Deep-mine coal - low methane	10 m^3/Mg coal produced
Deep-mine coal - high methane	25 m^3/Mg coal produced
Opencast-mine - low methane	0.3 m^3/Mg coal produced
Opencast-mine - high methane	2.0 m^3/Mg coal produced

Post mining activities	
Underground coal mine - low methane	0.9 m^3/Mg coal produced
Underground coal mine - high methane	4.0 m^3/Mg coal produced
Opencast-mine - low methane	0.0 m^3/Mg coal produced
Opencast-mine - high methane	0.2 m^3/Mg coal produced

Emission factors relate to methane only. No data quality is given, although the default emission factor is based on a number of measurements, the variation is large. Use of the default emission factors would result in an estimate of data quality D.

Selection of high or low methane emission factor depends on the results of measurement data carried out at selected coalfields. If no data are available then the higher emission factor should be used.

According to information from Russia (Tsibulski 1995) there exists a strong time dependency of emission factors for post mining activities. The above emission factors for post-mining activities relate to combined storage and transport.

There are limited data available on the components of firedamp other than methane. A default profile is given in section 9. This suggests that the maximum concentrations of components other than methane are:

NMVOC	8% ethane (by volume), 4% propane (by volume)

CO_2 6% (by volume)

If 1m^3 methane has a mass of 680g, then

0.08 m^3 ethane has a mass of 102g

0.04 m^3 propane has a mass of 74.8g

0.06 m^3 carbon dioxide has a mass of 112.2g

No information is available on the accuracy or uncertainty of this data and so the data quality is E.

8.2 Detailed Methodology

The range of emission factors is refined, based on country specific data, and where possible mine-specific data. IPCC (1995) gives the following country specific data:

Country	**Emission factor m^3/Mg**
Former Soviet Union	17.8 - 22.2
United States	11.0 - 15.3
Germany	22.4
United Kingdom	15.3
Poland	6.8 - 12.0
Czech Republic	23.9
Australia	15.6

The following table contains emission data from Russia (Tsibulski 1995) on the main gases from coalmines. Methane emissions data were obtained on the basis of the average natural methane content of a coal seam and the quantity of coal extracted by underground mining. Natural methane content of a seam refers to the amount of methane contained in a virgin seam.

Coal Field	Average Natural Methane Content of Seams, m^3/t	Total Methane Resources, billion m^3	Number of mines	Emission of Fire-damp, billion m^3/year	
				CH_4	CO_2
1	17	13186	67	1381	257
2	8	4	28	20	90
3	18	1962	18	794	66
4	6	5.4	10	71	38
5	15	10	14	5	27
6	6	9	2	11	3.5
7	18	122.4	1	2	4
8	18	41382	1	0.2	0.3
9	10	12	2	0.1	10
10	10	142.5	1	0.1	2.5
11	12	8410	2	0.8	0.5
12	10	190	2	2	9
13	12	296	1	0.1	0.4
14	13	132	2	1.5	2
15	9	96	13	15	19
16	12	18	11	30	20
17	9	2	12	6.5	8.5
18	8	6	4	1.7	0.9

The following table contains average emission factors from Poland (Gawlik 1994) and Czech Republic (Fott et al.1998)

Compound	**Plant type**	**Emission factor m^3/Mg**	**Data quality**	**Abatement type**	**Abatement efficiency**	**Country**	**Ref**
CH_4	underground mining	6.01	A			Poland	[5]
CH_4	underground mining	17.6	A			Czech Republic	[6]
CH_4	post mining treatment and storage	1.55*	B			Poland	[5]
CH_4	open cast mining	0.019	B			Poland	[5]

* refers only to hard coal (for open cast mining the proposed emission factor = 0 m^3/Mg)

The detailed methodology also takes into account the use of firedamp as a fuel.

9 SPECIES PROFILES

The following profile of firedamp has been presented in a paper to the UK Watt Committee (Williams 1993).

Species	% content
Methane	80 - 95%
Ethane	0 - 8%
Propane and Higher Alkanes	0 - 4%
Nitrogen	2 - 8%
Carbon Dioxide	0.2 - 6%
Argon	trace
Helium	trace
Hydrogen	trace

The quality of this data is not known. It is assumed that % content relates to volume to volume.

Profiles from Russia (Tsibulski 1995) are as follows:

Mine	**H_2**	**CH_4**	**C_nH_{2n+2}**	**CO_2**	**N_2**	**O_2**
1	-	62	0.31	1	31.6	5.1
2	0.24	89.6	5.16	0.1	4.3	0.3
3	0.07	60.7	3.22	1.2	28.4	6.4
4	-	34.7	0.58	0.9	51.5	12.3
5	-	77.2	0.06	0.5	17.6	4.7

10 UNCERTAINTY ESTIMATES

10.1 Methane

Uncertainty in the activity statistics is very low since national data on tonnage of coal produced is generally considered to be very accurate. Uncertainty in the default emission factors for the simpler methodology is high given the range of emission factors in the data, approximately +/- 50%. Uncertainty in the emission factors for the detailed methodology is likely to be much less, in some cases less than +/- 25%.

10.2 Other components

Uncertainty for components other than methane is very high, due to the lack of data on the composition of firedamp. Uncertainty is considered greater than a factor of 2.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The priority area for improvement is to provide accurate information on the composition of firedamp, particularly the light hydrocarbon content. This is likely to vary considerably between coalfields.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Desegregation should be based on the information about territorial units in which the processes occur, and on the production of coal per given territorial unit.

13 TEMPORAL DISAGGREGATION CRITERIA

It may be assumed that emissions occur over 24 hours and consistently throughout the year.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

The IPCC Guidelines for National Greenhouse Gas Inventories should be referred to when estimating emissions.

16 VERIFICATION PROCEDURES

Verification is primarily through provision of national measurement data at representative coalfields. In addition, the validity of measurements can be gauged through comparison with results form other countries.

17 REFERENCES

[1] IPCC (1995) Guidelines for National Greenhouse Gas Inventories. Greenhouse Gas Inventory Reference Manual.

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[7] Takla G., Novacek P., Emission of Mine Gases in the Ostrava-Karvina district, In: Proceedings of conference “Emissions of Natural Gas”, CPNS Praha, May 1997

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE :

050200
050201
050202
050300
050301
050302
050303

SOURCE ACTIVITY TITLE :

Extraction, 1st Treatment and Loading of Liquid Fossil Fuels
Land-based Activities
Off-shore Activities
Extraction, 1st Treatment and Loading of Gaseous Fossil Fuels
Land-based Desulfuration
Land-based Activities (other than Desulfuration)
Off-shore Activities

1 ACTIVITIES INCLUDED

These SNAP codes cover the emissions from sources in connection with the extraction and preliminary treatment of liquid and gaseous fossil fuels. This includes extraction, first treatment and loading of gaseous and liquid fossil fuels from on-shore and offshore facilities. Flaring and combustion of fossil fuels are not included in this section (see SNAP code 090206 and SNAP sectors 1 - 3).

The fugitive losses from production facilities, first loading of crude fuels, and gas processing plants prior to the national or international gas distribution systems are also included.

Subsequent loading and distribution of fuels are considered under SNAP codes 050400 and 050600. Note that production and transport facilities may not be associated with the same countries as the first treatment facilities. For example a gas production platform may be in a Norwegian field, but the gas received at a terminal in Germany.

The current section covers the following activities which may take place on land or offshore:

- cold venting,
- fugitive emissions from production platforms,
- crude oil stabilisation
- glycol regeneration,
- storage tanks associated with the production facility,
- tanker loading,
- drilling muds,
- waste water,
- test drilling,
- losses during transport in marine tankers and oil pipelines and losses from gas pipelines up to the beginning of a national or international distribution network.

A number of facilities produce both oil and gas concurrently and the techniques are quite similar. Hence, five SNAP codes are described this chapter.

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution to national emissions from extraction and first treatment varies considerably, but in countries where oil and gas are extracted, they are invariably an important contributor to the national total of NMVOCs and methane.

Table 2.1: Contributions to National Emissions from Oil & Natural Gas Production (EDGAR, 1990)

Country	%NMVOC	%Methane	Year
Canada	23 %	37 %	1990
United States	3.6 %	29 %	1990
Latin America	14 %	1.3 %	1990
Africa	8.2 %	5.1 %	1990
Norway *	34 %	3 %	
UK *	3 %	2 %	
Western Europe	8.7%	15 %	1990
Eastern Europe	5.4 %	31 %	1990
Russia *	40 % (total VOC)		
Middle East	53 %	2.2 %	1990
Japan	0.1 %	6.8 %	1990

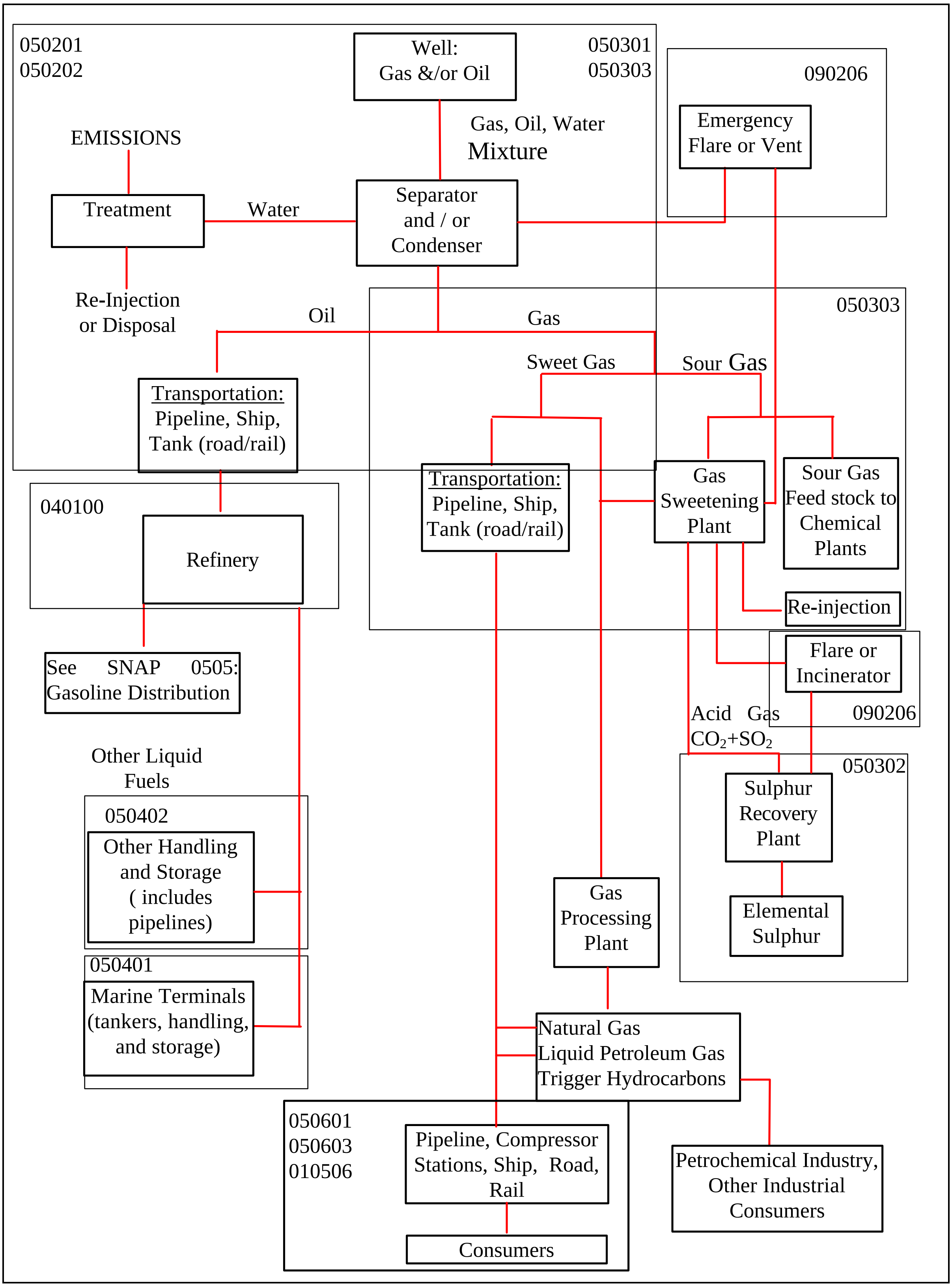
* Emissions are specific to extraction, first treatment, and loading of liquid and gaseous fuels.

3 GENERAL

The extraction and first treatment of liquid and gaseous fuels involves a number of activities, each of which represents a potential source of hydrocarbon emissions. Since not all activities are carried out at a specific site, the following descriptions have been prepared by type.

3.1 Description

Figure 3.1 below is a flow diagram that illustrates the activities covered in this section and their relation with activities covered in other sections of the guidebook.



3.1.1 Combined oil and gas facilities

Production platforms handle the reception, treatment and export of well fluids. Crude oil is usually de-watered and gas is processed for platform use, re-injection, or export as required. The process system on production platforms consists of :

Separation of crude oil, gas and water and subsequent export
Gas treatment and export
Produced water handling
Pressure relief and blow down
Utilities (energy supply etc.)
Injection systems for gas and oil
Crude oil stabilisation
Desulphurisation of gaseous fuels (usually land based)

3.1.2 Facilities producing gas only

These facilities do not have crude oil separation and export. The produced water handling systems are not present or partially present.

3.1.3 Facilities producing oil only

These facilities do not have gas treatment and export process systems. However there are few examples of facilities with absolutely no gas production.

3.1.4 Gas terminals

The typical gas terminal facility receives gas by pipelines, and conditions the gas ready for export to the national or international distribution network. Gas conditioning includes: separation, CO_2 and hydrogen sulphide removal, hydrogen sulphide incineration, pressure relief and blowdown systems.

3.1.5 Oil loading and transport

This source includes the transfer of oil or liquefied gas from storage tanks or directly from the well into a ship or another container specifically for transport away from the production site. This activity also includes losses during transport.

3.1.6 Pipelines

Oil and gas is commonly transported from oil and gas facilities to terminals by pipelines. These may cross national boundaries.

3.1.7 Drilling

Drilling of wells involves the use of specially formulated drilling muds which may contain organic solvents. When the drilling breaks through small oil/gas reservoirs emissions may result.

3.2 Definitions

Flaring:	Open combustion of gases from a “flare stack” without utilising the energy
Facility:	Oil and natural gas platforms, terminals, etc.
Fugitive losses:	Emission of hydrocarbon vapours from process equipment and evaporation of hydrocarbons from open areas, rather than through a stack or vent. Includes emissions from valves, connectors, flanges, seals, process drains, oil/water separators, storage, transfer operations, etc.
Glycol regeneration:	A process that reduces the water content in glycol by heating and gas stripping.
Sm^3(Standard cubic meter):	1 m^3 of gas at 15^{o}C and 1 atm pressure (1.01325 bar).
Venting:	Direct, controlled, release of gas to the atmosphere.
Stripping gas:	Gas used to promote reduction of an unwanted component in a fluid (e.g. remove water in glycol regeneration and oxygen from water injection system).

3.3 Techniques

The technology for the extraction and first treatment of liquid and gaseous fossil fuels are described in sections 3.1. and 3.4.

3.4 Emissions/Controls

3.4.1 Combined oil and gas facilities

The emissions from combined oil and gas facilities may be categorised as direct venting of gas into the atmosphere, fugitive losses and evaporation from contaminated waste water.

Venting is a deliberate, direct release of gas from the various processes and is usually related to pressure relief and blow down systems to ensure safe operations. The operations which result in direct venting also include stripping gas from glycol regeneration, water treatment, relieved gas in seal oil systems, equipment depressurisation and other activities leading to venting.

Venting emissions may be reduced by flaring (incinerating) the gas. This is desired from a environmental point of view as methane is a more potent greenhouse gas per molecule than CO_2. Installation of recovery systems for atmospheric vents is also a possibility. The recovered gas may be exported, used on platforms or re-injected. Nitrogen may be used as purge gas instead of hydrocarbons.

Crude oil stabilisation involves the removal of the most volatile components of the crude oil. Stabilisation of crude oil occurs either on offshore platforms, or less usually, at terminals. Although the process has the potential to cause emissions of VOC, the United Kingdom

Offshore Operators Association (UKOOA) claim that emissions are in fact small since the volatiles are generally either used as fuel or are sent to flare rather than being vented directly to the atmosphere.

Desulphurisation of gaseous fossil fuels is the removal of hydrogen sulphide (H_2S) from the gas. See SNAP 040103 for description and emissions calculations

Fugitive emissions arise from several sources, in particular gas leakage through compressor seals, valves and flanges. These emissions may be reduced by implementing procedures for detecting leaks from the process systems, minimising leaks and spills through equipment changes, procedure changes, improved monitoring, house keeping, and maintenance practices.

Waste water separated from the oil/gas mixture is first cleaned before disposal. The cleaned water inevitably contains some organic compounds which may evaporate later. The organic compounds removed during cleaning may also evaporate.

3.4.2 Facilities producing gas only

These facilities are designed to sell the gas produced. Therefore, generally, there is less direct venting and flaring of gas. These facilities also produce less waste water. Control options are the same as those mentioned for the combined facilities described in 3.4.1.

3.4.3 Facilities producing oil only

All gas produced will either be flared, vented, used as fuels or re-injected into the reservoirs. Generally, at oil only facilities the crude oil/gas mixture reaching the surface will contain less gas than the mixture at combined or gas facilities. In general the methane content of vented gas is less than that found in gas producing facilities. Control options are the same as those mentioned for the combined facilities described in 3.4.1.

3.4.4 Gas terminals

The main emission sources are the flare at the pressure relief system associated with the compression unit, the vent from the gas drying operation and the stack from the H_2S-incinerator. There are also several fugitive sources, leakages through compressor seals, valves and flanges. The technologies and potential for reductions in emissions will be very similar to a gas production platform. An acid gas scrubber may be applied to the H_2S incinerator. Control options are the same as those mentioned for the combined facilities described in 3.4.1.

3.4.5 Oil loading and transport

Crude oil is transported from production operations to a refinery by tankers, barges, rail tank cars, tank trucks, and pipelines (next section). When oil is loaded, hydrocarbon vapour will be displaced by oil and new vapour will be formed, both leading to emissions. The mass emitted will depend on:

- the movement of the vessel - the greater the movement the greater the emissions
- the vapour pressure of the crude
- temperature of the crude - temperature should be as low as possible

- loading rate into each tank - the greater the loading rate the lower the emissions
- method of loading - splash, submerged, or bottom loading
- geometry of the tanks - the higher the surface area to volume the higher the emissions
- tank atmosphere, and
- crude oil washing procedures.

Although unloading in itself is a minor source compared to loading, procedures for unloading may influence the emissions while loading. Recovery systems will be available in the near future that will reduce the NMVOC emissions from off shore loading by about 70%. Technologies to reduce emissions from on shore loading are available. The efficiency is about 85%.(Methane emissions will not be reduced considerably).

Ballasting of marine vessels is another potential source of emissions. Ballasting losses are a major source of emissions from unloading at marine terminals. Ballasting does not occur with all vessels as many (and the new vessels) have segregated tanks where ballasting is not necessary and is even not in use in some countries (e.g. Norway).

Ballasting is the partial loading of cargo tanks after cargo is unloaded to improve stability of the vessel. Cargo tanks are typically ballasted to about 80 % of their capacity, resulting in 15 to 40 % of the vessel capacity. Emissions occur when the vapours present are displaced by the ballast water. The ballast water is then pumped out prior to loading thereby reducing the subsequent loading emissions. Emissions may be reduced by containing the vapours through displacing the ballasting vapours into a cargo tank that is simultaneously being unloaded. (US EPA, 1996)

3.4.6 Pipelines

Emissions may originate from connection points, valves and damaged sections. Emissions may be controlled by inspection procedures followed by repair and upgrading (further described in 3.4.1 under fugitive emissions).

3.4.7 Drilling

The main emission sources during drilling are penetration of shallow gas pockets, migration of reservoir fluid through the circulated drilling fluid, gas migration through poor casing and cement work, the use of oil or solvent based drilling muds, and the wash of oil contaminated cuttings. The main control options are gas removal during drilling and recovery of hydrocarbons from oil based muds and cuttings.

4 SIMPLER METHODOLOGY

Emissions may be estimated using general emission factors multiplied by the level of activity as described in section 6. Emissions from the various sub-sources mentioned in section 3.4 and 6 are estimated independently and added. Countries need to know the important features of their production systems to estimate the main sources of emissions.

5 DETAILED METHODOLOGY

The detailed methodology involves quantification of emissions by source using field specific activity statistics and emission factors or direct measurements/engineering calculations. Field studies in collaboration with industry will be required to more accurately quantify the emissions at specific sites. Many of the calculations are detailed within the simpler methodology. Emission factors exist for many of the emission sources such as: venting, fugitive sources, drilling, and transportation of fuels. Several calculation methods are available and are described in the subsections 8.1 and 8.2.

6 RELEVANT ACTIVITY STATISTICS

The material in the following sections for the simple and detailed methodology has been organised in a hierarchical manner, beginning with the easiest information to obtain going to the more detailed methods as the list progresses. It is recommended to obtain all of the information possible per facility or per m3 of gas produced by facility type, then calculate the emission using the requisite methodology.

6.1 Simple Methodology

For the simpler methodology the following activity statistics are required:

The number of facilities (platforms) - age and type.

Oil and gas production, preferably by field. These data are available from national statistical offices in each country and from various international sources such as the OECD and CASPER (see section 15).

The heat content of the oil and gas and density of the oil.

The volume of gas processed through a gas terminal - will be available from national sources.

The mass of crude oil loaded into tankers (ships or trucks). This mass will in many cases be equal to the oil production at a specific field.

The frequency of drilling operations (the number of wells drilled per year or the total number of days drilled per year).

The volume of gas or oil transported through a given pipeline - this volume is measured for economical reasons or it might in many cases be equal to the combined production from a number of fields.

The mass and composition of drilling muds

6.2 Detailed Methodology

For the detailed methodology the following field specific activity statistics are required in addition to the above information described in the simple methodology:

The volume of gas vented.

The composition of the gas vented and its average molecular weight.

The component count of the gas handling system (e.g. number of valves, flanges and seals, etc.).

The volume of H_2S gas incinerated or the sulphur content of the gas.

Average true vapour pressure of liquid loaded onto ships, Reid Vapour Pressure (RPV), average molecular weight of vapours, density of condensed vapours, and average temperature of vapours for oil being transported from each field.

7 POINT SOURCE CRITERIA

The location of oil and gas production facilities are associated with specific oil and gas fields. Where practical individual fields and production facilities should be considered as point sources.

All pipelines, ships and trucks in movement should be considered as line sources.

All gas terminals should be considered as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

The following sections detail the simpler methodology for the calculation of emissions. Though this is the simple method some of the calculations for emission sources are quite detailed. The calculations have been arranged from the simpler to the more detailed. Methods used to calculate the emissions should be based on the available information.

For some of the calculations other sections of the Atmospheric Emissions Inventory Guidebook will be required. These sections are, but, not limited to the following:

- Desulphurisation SNAP 040103
- Flaring SNAP 090206
- Combustion of fuels SNAP sectors 1 - 3
- Loading of storage tanks and trucks SNAP 040104
- Liquid Fuel Distribution SNAP 050400
- Gas distribution networks SNAP 050600

Care must be taken when using the emission factors listed in the following sub-sections. They contain a high degree of uncertainty, and are only provided to indicate the relative differences that exist between the countries. Further investigation of the emission rates is required to determine the type of facilities they represent, and the extend of possible double counting. These emission factors should be used if no other sources of information are available.

8.1.1 Combined oil and gas facilities

The following tables list the emission factors for venting per facility and per Smillion m^3 of gas produced.

Table 8.1: Suggested Emission Factors for Venting (kg/Smillion m^3 gas produced) (OLF, 1993)

	NMVOC	CH_4	CO_2	Quality codes
Norway	76	98	0	C

Table 8.2: Suggested emission factors for venting (Mg per facility) (OLF, 1993; UKOOA 1995)

	NMVOC	CH_4	CO_2	Quality codes
Norway	30	20	0	C
UK	550	660	70	C

Generally, the venting will be higher on older platforms than on newer platforms. The main reasons for the difference are: recent platforms have employed the use of low pressure systems, more recovery of hydrocarbon gases, use of electric start turbines rather than gas driven and moving away from the practice of venting. If better data is not available, the highest suggested emission factor should be applied.

Suggested emission factors for fugitive losses:

The following equation has been suggested for installations in USA (Countess et al, 1993), which seems to be in reasonable agreement with estimates for Norway and UK.

$$\textbf{Total VOC (Mg/year)} = 40.2 * N + 1.1 * 10^{-2} * X + 8.5 * 10^{-6} * Y \qquad (1)$$

Where: N is the number of facilities (e.g. platforms)
X is the gas production (million Sm^3/year)
Y is the oil production (mill Mg/year)

Of the total VOC, a composition of 75 % methane and 25 % NMVOC may be assumed if better data is not available.

If the technology is old, emissions may be higher than estimated by this equation.

8.1.2 Facilities producing gas only

The tables below list emission factors for entire facilities for the extraction, first treatment, and loading of gaseous fuels. The Emission Factors are of 3 types: general (SNAP 050300), onshore (SNAP 050302), and offshore (SNAP 050303) activities. Care must be taken when using these emission factors due to the high degree of uncertainty. It is recommended to use the detailed procedure in section 8.2.2.

For desulphurisation see SNAP 040103.

Table 8.3: General Facility Emission Factors for Combined Extraction, First Treatment and Loading (CORINAIR, 1990)

	NMVOC Emissions / Unit Production		**Quality**
	g / m^3	t / PJ *	
Poland	3.1	82	C

* Assumed heat content of gas is 38 kJ / m^3

Table 8.4: Onshore Facility Emission Factors for Combined Extraction & First Treatment (CORINAIR, 1990)

	NMVOC Emissions / Unit Production		**Quality**
	g / m^3	t / PJ *	
Germany	0.079	2.1	C
Czech / France / Hungary **	3.1	82	C
Romania / Slovakia **	3.1	82	C
Bulgaria	0.001	0.024	C
Italy	0.009	0.24	C
Spain	0.34	9.0	C
UK	0.055	1.4	C

* Assumed heat content of oil is 38 MJ / m^3

** Emission rates may contain Methane

Table 8.5: Offshore Facility Emission Factors for Combined Extraction, First Treatment and Loading (CORINAIR, 1990)

	NMVOC Emissions / Unit Production		Quality
	g / m^3	t / PJ *	
Denmark **	0.14	3.9	C
Germany	0.079	2.1	C
Italy	0.009	0.24	C
Spain	0.34	9.0	C
Romania	3.1	82	C
Norway ***	0.097	2.6	C

* Assumed heat content of oil is 38 MJ / m^3

** Leakage offshore

*** Extraction of Natural Gas

The emission factors in Tables 8.3-8.5 should be used only if all other avenues have been exhausted.

Table 8.6: Suggested Emission Factors for Venting [Brown et al, 1993; Picard et al, 1992; SRI, 1994; TNO]

	NMVOC	**CH_4**	**CO_2**	**Unit**	**Quality**
UK	61	498	25	Mg/facility	C
Canada	0.19	0.33		Mg/Gg gas	C
Russia	1.4 -2.1			Mg/Gg gas	C
Netherlands	0.6	6.7	0.2	Mg/Gg gas	C

* Total VOC. Vent and fugitive losses

For fugitive losses Equation 1 (Section 8.1.1) will be relevant.

Table 8.7: Canadian Fugitive Emission Factors for Facilities. (Countess et al, 1993)

	NMVOC	**CH_4**	**Unit**	**Quality**
Canada	0.9	1.5	Mg/Gg gas	C

8.1.3 Facilities producing oil only

The tables below list emission factors for entire facilities for the extraction, first treatment, and loading of oil from onshore (SNAP 050201) and offshore (SNAP 050202) activities.

Table 8.8: Onshore Facility Emission Factors for Combined Extraction & First Treatment (CORINAIR, 1990)

	NMVOC Emissions / Unit Production		**Quality**
	kg / t	t / PJ *	
France / Bulgaria /Italy	0.10	2.4	C
Greece / Spain / Slovak	0.090	2.1	C

- Assumed heat content of oil is 42 GJ / t

Table 8.9: Offshore Facility Emission Factors for Combined Extraction, First Treatment and Loading (CORINAIR, 1990)

	NMVOC Emissions / Unit Production		**Quality**
	kg / t	t / PJ *	
Italy	0.10	2.4	C
Romania	0.10	2.4	C
Norway (1) **	0.58	14	C
Norway (2) **	2.0	47	C
UK	3.2	75	C
Spain	0.091	2.2	C

* Assumed heat content of oil is 42 GJ / t

** Norway (1) and (2) assumed to be 2 different facilities

The emission factors in Tables 8.8-8.9 should be used only if all other avenues have been exhausted.

Table 8.10: Suggested Emission Factors for Venting (Brown et al, 1993; Picard et al, 1992; SRI 1994, TNO)

	NMVOC	CH_4	CO_2	Unit	Quality
UK	300	270	240	Mg/facility	C
Canada	0.24	0.44		Mg/Gg oil	C
Russia	2.6			Mg/Gg oil	C
Netherlands	0.9	9.3	0.3	Mg/Gg oil	C

For fugitive losses equation 1 in section 8.1.1 will be relevant.

Table 8.11: Canadian Facility Level Emission Factors for Oil Production (Countess et al, 1993)

	NMVOC	CH_4	Unit	Quality
Canada[1]	0.6	1.1	Mg/Gg oil	C

8.1.4 Gas terminals

Table 8.12: Suggested Emission Factors for Venting (Gg/Terminal) Venting (Brown et al, 1993; Picard et al, 1992; SRI 1994, TNO)

	NMVOC	CH_4	CO_2	Throughput	Quality
UK[1]	0.28	2.4	0.034	-	C
Canada[2]	0.007	0.013	-	-	C
Norway[3]	0	0	0	25 bill. Sm^3	C
Russia[4]	5-12*		-	22 bill. Sm^3	C

* Including fugitive losses and methane

Table 8.13: Suggested emission factors for fugitive losses (Gg/terminal) Venting (Brown et al, 1993; Picard et al, 1992; SRI 1994)

	NMVOC	CH_4	Throughput	Quality
UK	0.04	0.47	-	C
Canada	0.03	0.05	-	C
Norway	0.76	0.44	25 bill. Sm^3	C

The UK has developed average fugitive emission rates of total hydrocarbons from onshore gas terminals and oil processing facilities. While probably conservative the values given should be used unless facility specific data is available.

Table 8.14: Average Fugitive Emission Factors for VOC from Onshore Gas Terminal and Oil Processing Facilities (UKOOA, 1993)

	Gas Terminal	**VOC**	**Quality**
Component	Average count	kg/a/component	
Connections	5546	18	C
Valves	1521	200	C
Pressure relief devices	39	120	C
Rotating shafts	41	530	C
Other	229	79	C

No data is currently available on emission factors for the H_2S scrubbing system, only for the flaring which often occurs after the scrubber, see SNAP 090206, and 040103.

8.1.5 Oil loading and transport

See also SNAP 050401 to 050404 for additional information on oil loading and transport. SNAP 040104 for loading of storage tanks and trucks

The following emission factors for fugitive emissions are percent by weight of the liquid loaded

Table 8.15: Fugitive Emission Factors for Oil Loading (%wt loaded) (OLF, 1993; UKOOA, 1995; Rypal K., 1997)

	Ships		**Rail cars / Tank trucks**		
	NMVOC	Methane	NMVOC	Methane	Quality
Norway: Off Shore	0.1 - 0.3 %	5 - 15 %			C
Norway: On Shore	0.02 - 0.06 %	5 - 15 %			C
UK	0.001 %	0.000018 %	0.00033 %	0.000058 %	C

The methane content of the vapour will depend mainly on the composition of gas. The evaporation rate will depend on the factors listed in section 3.1.5.

An evaporation rate of 0.01%, of which methane is 15% has been suggested for UK (E+P, 1994) in another publication.

An evaporation rate of 0.2-0.6 % has been derived for Russia (SRI, 1994).

The US has developed average emission factors from its detailed methodology for the loading, ballasting, and transportation of crude oil by rail tank car and tank trucks.(US EPA, 1996) As a last resort these could be applied to marine transportation of oil on ships or barges, but, every attempt should be made to utilise as much of the detailed methodology as possible.

Table 8.16: Uncontrolled VOC Emissions Factors for Crude Oil Rail Tank Cars and Tank Trucks (US EPA, 1996)

Emission Source		VOC [a, b]	Units
Loading Operations [c]	Submerged: Dedicated Normal Service	240	g / m^3 transferred
	Submerged Vapour Balance Service	400	g / m^3 transferred
	Splash: Dedicated Normal Service	580	g / m^3 transferred
	Splash Vapour Balance Service	400	g / m^3 transferred
Ballasting Operations	No displaced vapour transfer	130	g / m^3 water ballast
Transit Losses [d]		4.3	kg / week-m^3 shipped

a NMVOC may be assumed to be 85 % of the emissions calculated with the remainder ethane and methane, if speciation data is not available.

b The example crude has an RVP of 34 kpa (5 psia).

c Loading emission factors calculated using equation 8 (Section 8.2.5) for a dispensed product with temperature of 16 °C.

d The example crude assumed to have condensed vapours with an approximate density of 0.6 kg / m^3 (rough estimate).

8.1.6 Pipelines

For Russia an emissions factor of 0.07-0.2 Mg/Gg gas/100 km pipeline (depending on the diameter (0.4.1.4 m)) has been derived (SRI, 1994).

Tables 8.17-8.19 list emission factors from CORINAIR 1990 for emissions from distribution networks. The tables are for gaseous fuels and liquid fuel distribution. Note that the emission factors are for On Shore networks and the rates would be lower for Off Shore. See also the SNAP sections 0504 and 0506 for further information. Care must be taken when using these emission factors due to the high degree of uncertainty associated with them. They are provided only to indicate the relative differences that exist between the countries and further investigation of the emission rates is required to determine the type of facilities they represent, the extend of possible double counting.

Table 8.17: Emission Factors for Gas Distribution (CORINAIR, 1990)

Process	**Country**	**NMVOC Emissions / Unit Production**		**Quality**
		g / m^3	t / PJ *	
General	Poland	2.6	68	C
	Spain	1.1	109	C
	Luxembourg	0.45	12	C
Pipelines	Denmark, Lithuania	0.014	0.37	C
	Italy	0.016	0.42	C
	Latvia	0.003	0.084	C
Compressor	France		2.5	C
	Germany	0.079	2.1	C
	Italy	0.054	1.4	C
	Swiss		0.10	C
Networks	France		10	C
	Italy	0.88	23	C
	Denmark, Lithuania	0.87	23	C
	Slovak	0.072	1.9	C
	Swiss	0.76	20	C
	UK	0.62	16	C

* Assumed heat content of gas is 38 MJ / m^3

Table 8.18: Emission Factors for Crude Oil Distribution (CORINAIR, 1990)

Process	**Country**	**NMVOC Emissions / Unit Production**		**Quality**
		kg / t	t / PJ *	
Marine Terminals	Bulgaria, Germany	0.02	0.48	C
	France, Greece, Italy, Poland, Portugal	0.30	7.1	C
	Lithuania	0.023	0.62	C
	Spain	0.27	6.5	C
Other Handling and Storage	Bulgaria, Greece, Hungary, Italy, Luxembourg, Poland, Romania, Spain	0.020	0.48	C
	Norway	1.1	26	C
	Portugal	0.18	4.3	C

* Assumed heat content of oil is 42 GJ / t

Table 8.19: Canadian Emission Factors for Fugitive Emissions (Mg/Gg transported) (Picard et al, 1992)

	NMVOC	**Methane**	**Quality**
Crude oil systems	0.072	0.13	C
Natural gas systems	0.054	0.095	C

8.1.7 Drilling

The emission from drilling operations includes the usage of the solvents in the drilling muds and from fugitive sources, such as blow by from small trapped pockets of gas.

Use of drilling mud:

UK 50 kg/Mg of solvent[1]

1. The solvent usage in drilling muds in UK is estimated at 50 Gg per year (Passant 1993)

Table 8.20: Fugitive Emissions from Drilling Process (OLF, 1993; Picard et al, 1992)

	NMVOC	CH_4	Unit	Quality code
Norway	700	325	kg/well drilled	C
Canada	1837	3238	Mg total*	

* The number of wells is not known

Emissions from venting in connection with well testing are not included in these emission factors, but should also be estimated whenever possible.

Emissions from combustion of crude at test platforms is also not covered under this section, please see the appropriate SNAP code.

8.2 Detailed Methodology

The detailed methodology provides guidance to improve the estimates generated with the emission rates given in the simpler methodology (section 8.1). The detailed methodology should be used in conjunction with the simple methodologies and is available for most sources except for drilling muds and gas terminals.

8.2.1 Combined oil and gas facilities

For venting, the volume of gas vented should be established for each field and combined with the specific composition data for each field. If the specific composition of the gas vented is not known, use the average molecular weight and the equations developed by UK below.

$$\textbf{Total Vented NMVOC (kg/year)} = 5 * MW * V / 224 \quad (4)$$

$$\textbf{Total Vented Methane (kg/year)} = 5 * MW * V / 224 \quad (5)$$

Where: MW is the average molecular weight of the gas vented
V is the volume of gas vented in Standard cubic meters

For fugitive emissions the component counts are required for each platform. These are to be combined with internationally accepted emission factors, e.g. API. However, verification of these are required for the particular installation to take into account current technologies.

The following emission factors have been suggested by the UK for average fugitive emissions of total hydrocarbons for facilities with state of the art leak detection and control programmes. The emission factors are kilograms of emissions per component per year with VOC and Methane factors derived from gas composition data.

Table 8.21: Average Fugitive Emissions of Total Hydrocarbons for Facilities With State of The Art Leak Detection and Control Programmes (UKOOA, 1995)

	Connection	**Valves**	**Open-Ended Lines**	**Others**
	kg/a/component			
Offshore oil and gas	0.099	3.5	1.6	17

Fugitive emissions may also be estimated by tracer measurements techniques.

The estimation of emissions from water treatment will require an exact knowledge of the volume of water treated, treatment method, the oil content of the discharged water, and the actual mass of water emitted to the atmosphere.

8.2.2 Facilities producing gas only

See section 8.1.2 except for gas venting if the specific composition of the gas is not known. The following has been developed by the UK for facilities producing gas, venting gas:

$$\textbf{Total Vented NMVOC (kg/year)} = 9 * MW * V / 224 \quad (6)$$
$$\textbf{Total Vented Methane (kg/year)} = 1 * MW * V / 224 \quad (7)$$

Where: MW is the average molecular weight of the gas vented
V is the volume of gas vented in Standard cubic meters

The following emission factors have been suggested by the UK for average fugitive emissions of total hydrocarbons. The emission factors are in kilograms of emissions per component per year with VOC and Methane factors derived from gas composition data.

Table 8.22: Facilities With State-Of-The-Art Leak Detection and Control [11]

	Connection	**Valves**	**Open-Ended Lines**	**Others**
	kg/a/component			
Offshore gas	0.63	18	1.8	48

Table 8.23: Offshore Facilities With Conventional Leak Detection and Control (UKOOA, 1995)

	Connection	**Valves**	**Pressure relief devices**	**Rotating shafts**	**Others**	**Quality**
	kg/a/component					
Gas production	11	29	24	200	65	C

For the facilities with conventional leak detection use may be made of the following table of component counts in hydrocarbon service on the generic platforms, estimated from CAD designs by the UK

Table 8.24: Generic Platform Component Counts for Conventional Leak Control (UKOOA, 1995)

Facility type	**A**	**B**	**C**	**D**	**E**	**Quality**
Connections	1114	2363	2792	3483	8289	C
Valves	514	1348	1036	1572	3002	C
Pressure relief devices	3	32	27	43	65	C
Other	110	357	311	270	557	C

Notes: Generic A Well head gas platform 150 MMSCFD
Generic B Gas treatment/compression platform 330 MMSCFD
Generic C Small simple oil platform 40000 BPD & 10 MMSCFD
Generic D Medium complexity oil platform 75000 BPD & 16 MMSCFD
Generic E Large oil/ condensate platform 80000BPD & 540 MMSCFD

8.2.3 Facilities producing oil only

See section 8.1.3 also for additional information

The following emission factors have been suggested by the UK for average fugitive emissions of total hydrocarbons. The emission factors are in kilograms of emissions per component per year with VOC and Methane factors derived from gas composition data.

Table 8.25: Facilities With State-of-The-Art Leak Detection and Control [11]

	Connection	**Valves**	**Open-Ended**	**Others**	**Quality**
	kg/a/component				
Offshore light crude	0.68	3.3	5.8	16	C
Offshore heavy crude	0.017	0.033	0.17	0.17	C

Table 8.26: Offshore Facilities With Conventional Leak Detection and Control [11]

	Connection	**Valves**	**Pressure relief devices**	**Rotating shafts**	**Others**	**Quality**
	kg/a/component					
Oil Production	7.1	36	1.5	130	14	C

Component counts from table 8.24 section 8.2.2 maybe used as estimates with the conventional leak detection and control emission factors

8.2.4 Gas terminals

Emissions from individual gas terminals should be determined separately through measurements, if possible, and engineering calculations as described in sections 8.2.1.

8.2.5 Oil loading and transport

Individual emission factors should be developed to reflect the variations mentioned in section 3.4.

It may be noted that Norwegian studies (OLF, 1993) have concluded the following:

> An amplitude of +2 degrees of the vessel while loading increases the mass of released gas by 50 % compared to calm conditions.
>
> An increase in the loading rate of 40 % decreases the mass of released gas by 14%.
>
> An increase in the temperature to 30 C to 34 C increases the mass of released gas by 10 %.

The US - EPA has developed an equation for the emissions from loading petroleum liquid into different transportation vessels (US EPA, 1996). For further information it is recommended to see the US-EPA AP-42 Sections 5.2 Transportation and marketing of petroleum Liquids, and 7.1 Organic Liquid Storage Tanks which contain further explanations as well as look-up tables for hydrocarbons. The Internet World Wide Web Site for the US-EPA emission factor information is http://www.epa.gov/ttn/chief/

$$\mathbf{L_L = 0.82947 * \frac{S * P * M}{T}} \qquad (8)$$

Note: The constant has been converted for metric use

Where L_L is the emission factor in kg / m^3 (± 30 %).

S is the Saturation Factor from table 8.29 below.

P is the true vapour pressure of the liquid loaded in pounds per square inch (1 psi = 6.89476 Pascal).

M is the molecular weight of the vapours (kg/kg-mole)

T is the temperature in Kelvin (^{o}C + 273)

P & M can be calculated using weighted averages of the molar ratios of the constituent components of the liquid loaded.

Table 8.27: Saturation Factors for Calculating Petroleum Liquid Loading Losses (US EPA, 1996)

Cargo Carrier	**Mode of Operation**	**S Factor**
Tank trucks and rail tank cars	Submerged loading: of a clean cargo tank	0.50
	Submerged loading: dedicated normal service	0.60
	Submerged loading: dedicated vapour balance service	1.0
	Splash loading: of a clean cargo tank	1.45
	Splash loading: dedicated normal service	1.45
	Splash loading: dedicated vapour balance service	1.00
Marine vessels *	Submerged loading: ships	0.2
	Submerged loading: barges	0.5

* For products other than crude oil. For marine loading of crude oil use equations 10 & 11 and table 8.30

The saturation factor S represents the expelled vapour's fractional approach to saturation, and it accounts for the variations in emission rates from the different unloading and loading methods.(US EPA, 1996)

The emissions from controlled loading operations can be calculated by multiplying equation 8 with equation 9 below which accounts for the reduction efficiency (as a percentage) of the control method. The efficiencies of the control methods often range from 90 to 99 %, but due to limitations only 70 to 90 % of the vapour is captured. Due to the limitations 90 % should be used when the tankers pass regular inspections, otherwise 70 % should be assumed. (US EPA, 1996).

$$\textbf{Reduction} = (1 - \text{eff.} / 100) \qquad (9)$$

Where eff = efficiency of control method

For Marine Crude oil loading the following has been developed by the US-EPA specifically for loading of crude oil into ships and barges. (US EPA, 1996)

$$C_L = C_A + C_G \qquad (10)$$

Where: C_L is the total loading loss in kg / m^3 of crude oil loaded.
C_A is the arrival emission factor, contributed by vapours in the empty tank compartment before loading in kg / m^3, table 8.30.
C_G is the generated emission factor contributed by evaporation in kg / m^3.

Table 8.28: Average Arrival Emission Factors, C_A, for Crude Oil Loading Emissions[a] (US EPA, 1996)

Ship / Ocean Barge Tank Condition	Previous Cargo	Arrival Emission Factor, kg/m^3
Uncleaned	Volatile[b]	0.103
Ballasted	Volatile	0.0551
Cleaned or gas-freed	Volatile	0.0395
Any Condition	Non-volatile	0.0395

a Arrival emission factors (C_A) to be added to generated emission factors (C_G) calculated in equation 11 to produce total crude oil loading loss (C_L). Factors are for total organic compounds; NMVOC emission factors average about 15% lower, because VOC does not include methane or ethane.

b Volatile cargos are those with a true vapour pressure greater than 10 kPa (1.5 psia).

The generated emission factor equation (11) below was developed empirically from test measurements of several vessel compartments.

$$C_G = 0.12249 * (0.44 * P - 0.42) * \frac{M * G}{T} \qquad (11)$$

Note: The constant has been converted for metric use

Where P is the true vapour pressure of loaded crude oil in psia (pounds per square inch absolute)

M is the molecular weight of the vapours

G is the vapour growth factor = 1.02 (dimensionless)

T is the temperature of the vapours in Kelvin (^{o}C + 273)

Emission factors (C_G) derived from equation 11 is for total organic compounds. NMVOC has been found to be 55 to 100 weight percent of the vapours from crude oil in the US. If specific vapour composition is unavailable 85 % of the emission factor may be used for NMVOC. (US EPA, 1996)

Ballasting losses may be estimated from the following equation from the US-EPA. (US EPA, 1996)

$$\mathbf{L_B = 0.0371 + 0.0240 * P + 0.00120 * P * U_A} \qquad (12)$$

Note: The constant has been converted for metric use

Where L_B is the ballasting emission factor kg / m^3 of ballast water

P is the true vapour pressure of discharged oil in psia.

U_A is the arrival cargo true ullage, before dockside discharge, measured from the deck in feet, (ullage here refers to the distance between the cargo surface and the deck level, 1 foot = 0.3048 m).

Average VOC emission factors are give in Table 8.29 below for ballasting into uncleaned crude oil compartments. The fully loaded category applies when the crude oil true ullage just before unloading is less than 1.5 metres. The lightered or previously short loaded category applies to compartments with an arrival ullage of greater than 1.5 metres. These values should only be used when the information for equation 12 is unknown.

Table 8.29: Total Organic Emission Factors for Crude Oil Ballasting. (US EPA, 1996)

Compartment Condition Before Cargo Discharge	**Average Emission Factors**	
	By Category	Typical Overall [b]
	g/m^3 Ballast Water	
Fully Loaded [c]	111	129
Lightered or Previously Short Loaded [d]	171	

a Assumes crude oil temperature is 16 ^{o}C and RVP of 34 kPa (5 psia). NMVOC emission factors average about 85% of emission factors listed as NMVOC does not include methane or ethane.

b Based on observation that 70% of tested compartments had been fully loaded before ballasting. May not be represent average vessel practices.

c Assumed typical arrival ullage of 0.6 m.

d Assumed typical arrival ullage of 6.1 m.

Transit losses also occur and the losses are similar to breathing losses for storage tanks (SNAPs 040102 and 050401). Testing in the US on ships and barges indicates that transit losses may be calculated with the following equation: (US EPA, 1996)

$$\mathbf{L_T = 1.436 * P * W} \qquad (13)$$

Note: The constant has been converted for metric use

Where L_T is the transit loss form ships and barges in kg / week-m^3.

P is the true vapour pressure of the transported liquid in psia.

W is the density of the condensed vapour in kg / m^3

8.2.6 Pipelines

Little data is currently available for this source.

Picard 1993 gives some emission factors related to individual sources (valves, seals, compressors, connectors etc.). See reference 6 for additional information to that provided below.

Table 8.30: Summary of Average Emission Factors for Uncontrolled Fugitive VOC Emissions (kg/h/source) at Upstream Oil and Gas Facilities in Alberta, Canada (Picard et al, 1992)

Source	Service Type	Oil Facilities	Gas Facilities	Quality
Valves [a]	All	0.0061	0.018	C
	G/V (All)	0.014	---	C
	G/V (Sweet)	---	0.044	C
	G/V (Sour)	---	0.0052	C
	LL	0.0012	0.0023	C
Connectors	All	0.00048	0.0013	C
	G/V (All)	0.00079	---	C
	G/V (Sweet)	---	0.0025	C
	G/V (Sour)	---	0.00031	C
	LL	0.00019	0.00019	C
Compressor Seals [2]	G/V	0.80	0.80	C
Pump Seals	LL	0.021	0.021	C
Pressure Relief Devices	G/V	0.12	0.12	C
Open Ended Lines	All	0.0037	0.0037	C

G/V Gas/Vapour: the process fluid exists as a gas or vapour at the operating conditions (temperature and pressure) and contains less than 50 percent hydrogen by volume.

LL Light Liquid: the process fluid is a hydrocarbon liquid at the operating conditions hand has a vapour pressure of 0.3 kPa or more at 15°C.

HL Heavy Liquid: the process fluid is a hydrocarbon liquid at the operating conditions hand has a vapour pressure of 0.3 kPa or more at 15°C.

[1] The emission factors for valves account for leakage from the valve body and around the valve stem. Leakage down the pipe (e.g., leakage past the valve seat) is accounted for using the emission factor for open-ended lines.

[2] The emission factors for compressor seals are only applicable for uncontrolled sources (i.e., systems that do not use seal-leakage capture systems [e.g., use of barrier fluids wuth degassing reservoir and vent-to-flare system])

Table 8.31: Speciation profiles (mole percent on a moisture free basis) for Fugitive Emission from Production Facilities. (Picard et al, 1992)

	Dry Gas		Sweet Gas				Sour Gas		
Component	G[1,5]	DHY[2,6]	G[5]	V[3,7]	LL[4,8]	DHY[6]	G[1,9,10]	V[2,7]	LL[3,8]
N_2	1.0914	6.0450	0.6793	2.9668	0.0000	3.0022	0.6552	2.9668	0.0000
CO_2	0.2674	3.6656	.0.5814	1.3436	0.0000	6.3865	0.5608	1.3436	0.0000
H_2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.5460	0.0000	0.0000
C_1	97.4524	87.4598	91.8796	56.4205	0.0000	68.9410	88.6210	56.4205	0.0000
C_2	1.1439	2.8296	5.4263	15.2219	6.2600	11.4083	5.2339	15.2219	6.2600
C_3	0.0389	0.0000	1.0490	11.6300	60.4300	3.7118	1.0118	11.6300	60.4300
i-C_4	0.0018	0.0000	0.1291	2.6504	10.9300	3.2751	0.1245	2.6504	10.9300
n-C_4	0.0034	0.0000	0.1949	5.5796	16.4000	3.2751	0.1880	5.5796	16.4000
i-C_5	0.0004	0.0000	0.0254	1.2562	1.6600	0.0000	0.0245	1.2562	1.6600
n-C_5	0.0005	0.0000	0.0296	1.5784	1.4300	0.0000	0.0286	1.5784	1.4300
C_6	0.0000	0.0000	0.0060	0.9312	1.2000	0.0000	0.0058	0.9312	1.2000
C_{7+}	0.0000	0.0000	0.0000	0.4215	1.6800	0.0000	0.0000	0.4215	1.6800

(See notes for table 8.32)

Table 8.32: Speciation Profiles (mole percent on a moisture free basis) for Fugitive Emission from Production Facilities Continued. (Picard et al, 1992)

	Nat. Gas	**Conventional Oil**		**Heavy Oil (Primary)**		**Heavy Oil (Thermal)**		**Crude Bitumen**
Component	G[5]	G[1,11]	V[3,7]/LL[4]	G[13]	V/HL[12,13]	G[1,13]	V[3,13]/HL[12]	G[14]/V/HL
N_2	0.6793	0.6190	13.9989	0.1817	6.3477	0.1932	3.3516	0.0000
CO_2	0.5814	5.2430	0.3303	0.0859	0.6892	2.6094	16.1140	22.0000
H_2S	0.0000	0.0000	0.0000	0.0001	0.0000	0.0150	0.1439	0.0000
C_1	91.8796	73.2524	10.0100	98.0137	87.2337	72.9361	66.6600	70.0000
C_2	5.4263	11.9708	15.7274	0.9062	2.2616	1.9370	0.9490	8.0000
C_3	1.0490	5.3198	24.1601	0.0408	0.1905	3.0956	0.5394	0.0000
i-C_4	0.1291	0.8778	6.6404	0.0564	0.1324	1.0807	0.1922	0.0000
n-C_4	0.1949	1.7027	16.6022	0.0351	0.1137	2.3889	0.3678	0.0000
i-C_5	0.0254	0.3570	4.2113	0.0501	0.1400	1.9994	0.4541	0.0000
n-C_5	0.0296	0.3802	4.5447	0.0433	0.1230	2.2733	0.5829	0.0000
C_6	0.0060	0.2446	2.9655	0.0927	0.3949	5.8086	2.1914	0.0000
C_{7+}	0.0000	0.0327	0.7997	0.4940	2.4188	5.6628	8.4539	0.0000

[1] G - Gas.

[2] DHY - Vent gas from glycol dehydrators.

[3] V - Vapours from storage tanks.

[4] LL - Light Liquid.

[5] Based on a gas analysis taken at an appropriate transmission point.

[6] Estimated by simulating dehydration of the gas (G) at water-saturated conditions, 28°C and 7,000 kPa.

[7] Adapted from an analysis of the vapours from a condensate tank in northeast B.C.

[8] Estimated based on the total amount of ethane, propane, butane, and natural gas liquids produced by gas plants in 1989.

[9] The H_2S concentration is estimated based on the amount of gas and sulphur produced by sour gas processing plants in1989.

[10] The H_2S-free composition is based on an analysis taken at an appropriate transmission point.

[11] Based on an analysis of the gas from a large solution-gas gathering system in central Alberta.

[12] HL - Heavy Liquid.

[13] Adapted from results presented by Ullman et al. (1987)

[14] Provided by an operator of a major crude bitumen facility

8.2.7 Drilling

Specific emission factors for representative drilling wells should be developed taking into account the sources listed in section 3.4.7 and other possible sources.

9 SPECIES PROFILES

Speciation profiles for Crude Oil Production (US EPA, 1988) and natural gas venting (TNO) are listed in the profiles below. See also tables 8.33 and 8.34 given in section 8.2.6.

Table 9.1: Speciation Profiles

Species	**wt%**	
	USEPA	**TNO**
Ethane	6	72
Propane	19	14
Butanes	30	7
Pentanes	17	2
Hexanes	8	4
Heptanes	10	0
Octanes	7	0
Cycloparaffins	2	0
Benzene	0	0

The composition of the NMVOC fraction of emissions from oil and gas production can be expected to vary considerably between fields and between different emissions sources. Therefore, the above generalised species profiles should only be used if better information is not available.

10 UNCERTAINTY ESTIMATES

The quality of the emission rates provided in section 8 provides some indication of the uncertainty of the estimates that can be generated. Additional uncertainty guidance by activity is provided below.

Venting: An extremely high uncertainty is expected (greater than a factor of 2), particularly when the generalised emission factors are applied. The uncertainty may be as high as an order of magnitude in the emissions.
Fugitive emissions from oil and gas production platforms: An error of 65% has been reported for equation 1. However, this may be greater when this equation is applied to other fields. When using the general emission factors it can be seen that there is a variation of several orders of magnitude between countries.

Waste water treatment: The mass of oil in waste water discharged is normally measured accurately, particularly if it is a legal requirement. The proportion which evaporates is subject to much higher uncertainty (greater than a factor of 2).

The Norwegian data in general have estimated an uncertainty of +55%/-35% of the sum of vent and fugitive losses (OLF, 1993).

Gas terminal: Due to the few observations the uncertainty is expected to be greater than a factor of 2.

Oil loading and transport: The variation within existing data suggests that the uncertainty is greater than a factor of 2 when general emission factors are applied.

Drilling: Due to the few observations the uncertainty is expected to be greater than a factor of 2.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The variation in emissions of NMVOC and CH_4 from combined oil and gas and oil only production facilities in particular is expected to be large given the variation in the composition of the fluid and the options available to deal with the gas produced. Therefore, the weakest aspect of the simpler methodology is the use of generalised emission factors relating to oil production or the number of production facilities. Progress from the simpler methodology to the more detailed methodology is a priority. The main priority areas proposed for improvement are:

- All fields to report volume of vented gas and composition of vented gas.
- All fields to move from calculated estimates for the volume of gas vented, to measured data.
- All fields to report volume of oil loaded offshore, vapour pressure of the oil and the composition of the vapour.
- All installations to report fugitive emissions based on component counts, with selected fields providing verification through measurements.
- All gas terminals to report all emissions to atmosphere and carry out measurements to verify estimates for the major sources.
- The suggested emission factors are based on few measurements and detailed studies. More data from fields studies in different countries are needed in order to improve the general emission factors.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Currently “sea” is the only relevant NUTS code for offshore activities. If a higher spatial resolution is required or emissions are generated on-shore, production by field will be available in most countries.

Oil loading and gas terminal: These sources will generally be few, and the relevant activity statistics may easily be allocated to the correct territorial unit.

For pipelines, emissions may be assumed equally distributed along the pipe, if better information is unavailable.

13 TEMPORAL DISAGGREGATION CRITERIA

Monthly production data is available in major oil and gas exporting countries. If this information is not available, emissions may be assumed equally temporally distributed. Equal diurnal (night/day) may generally be assumed.

Oil loading can be expected to occur during the day only.

14 ADDITIONAL COMMENTS

There are a number of developments in emission estimate methodologies in this area e.g. IPCC, OLF (Norway) and OOA (UK).

This draft will have to be revised in the coming years in light of these developments.

Responsibility for emissions originating from fields shared between two countries: emissions are allocated from the economic shares of the countries in the current field.

15 SUPPLEMENTARY DOCUMENTS

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United Kingdom Offshore Operators Association Limited, Guidelines on Atmospheric Emissions Inventory. Issue No. 1, July 1995.

United States Environmental Protection Agency (US EPA), AP-42, 5th Edition, Compilation of Air Pollutant Emission Factors, Volume 1, Office of Air Quality Planning and Standards, Research Triangle Park, NC, January 1995.

16 VERIFICATION PROCEDURES

Covered in Section 11.

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE : **050401**
050402

SOURCE ACTIVITY TITLE : **Marine Terminals (Tankers, Handling and Storage)**
Other Pipeline and Storage (Including Pipelines)

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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SNAP CODES :

050500
050501
050502
050503

SOURCE ACTIVITY TITLES :

Gasoline Distribution
Refinery Dispatch Station
Transport and Depots (Except 050503)
Service Stations (Including Refueling of Cars)

1 ACTIVITIES INCLUDED

050501	Refinery dispatch station
050502	Transport and depots (except 050503)
050503	Service stations (including refuelling of cars)

Refinery dispatch station category includes emissions from filling of transport equipment (e.g. tank trucks) taking place within the refinery area. Transport and depots category includes emissions from transport equipment and from storage tanks outside refinery. Additionally emissions from Border Terminal Dispatch Stations should be considered under this SNAP code since in some countries the gasoline is not only produced in the respective country but also imported by pipelines, ships, barges and road tankers (Schürmann, 1994). Service stations category includes emissions from tanks at the station (e.g. during filling, withdrawal) and emissions while refuelling cars. For more details see section 3.4.

2 CONTRIBUTION TO TOTAL EMISSIONS

Table 2.1 shows the contribution of the gasoline distribution sector to total man-made NMVOC emissions reported in the CORINAIR’90 emission inventory. On average this sector (0505) contributes about 3.5%, of which about 2/3 are emissions from service stations. The contribution in different countries varies from less than 2%, e.g. in Bulgaria and Poland to as much as 7% in Slovenia. Table 2.2 shows the contribution of this sector to total emissions in different countries in Europe as presented in various emission inventories.

Table 2.1: Contribution to total man-made NMVOC emissions in Europe reported in CORINAIR’90 emission inventory.

Source-activity	**SNAP-code**	**Contribution (excluding emissions from nature) [%]**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Refinery Dispatch Station	**050501**	-	-	**0.2**	-	-	-	-	-
Transport and Depots	**050502**	-	-	**0.9**	-	-	-	-	-
Service Stations	**050503**	-	-	**2.3**	-	-	-	-	-

0 - emissions are reported, but the exact value is below the rounding limit of 0.1 percent
- - no emissions are reported

Table 2.2: Contribution of gasoline distribution sector to total man-made NMVOC emissions

Country/Region	Year	Reference	Contribution to total man-made NMVOC emissions [%]			
			050500	050501	050502	050503
OECD Europe	1980	OECD, 1990	4.4			
OECD Europe	1983	Edwards et.al,1986	5.2			3.6
EC	1985	Bouscaren, 1990	4.4			3.2
Ireland	1985	Bouscaren, 1990	4.2			3.7
Netherlands	1985	KWS2000, 1989	5.0			2.3
Slovenia	1988	Rode, 1993	6.7			
UK	1988	Passant, 1993	4.3			
UK	1990	CORINAIR'90	5.1		1.9	3.3
Slovakia	1990	Mareckova, 1994	3.9		0.5	3.4
Bulgaria	1990	CORINAIR'90	1.8		0.4	1.4
Ireland	1990	McGettigan, 1993	1.8		0.4	1.4
Poland	1990	Fudala, 1993a	1.5			
Poland	1992	Fudala, 1993b	2.5			

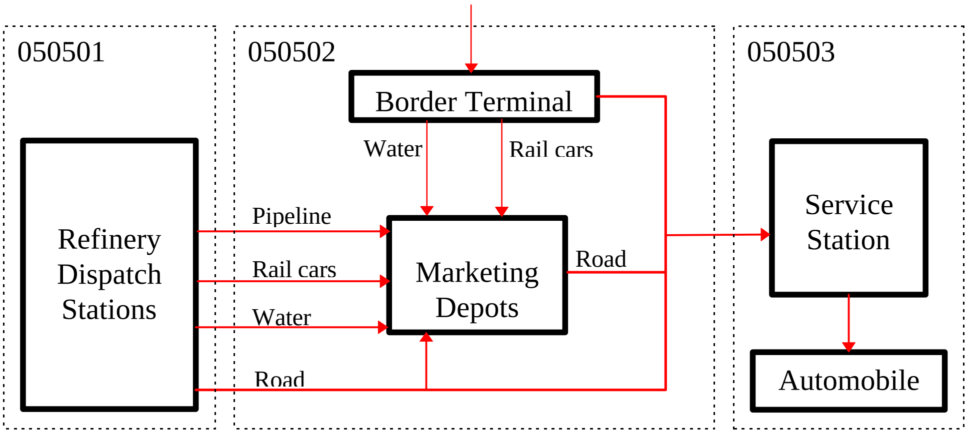
Nearly all of 28 countries participating in CORINAIR'90 inventory reported emissions from this sector including 10 countries reporting emissions from the sector 050501, 21 from 050502, and 24 from 050503.

3 GENERAL

3.1 Description

Gasoline distribution starts at the refinery dispatch station (050501) or at the border terminal dispatch station (050502) from where it is loaded into rail cars, barges, coastal tankers, pipelines for delivery to marketing depots (050502) or into road vehicles for delivery to service stations (050503) or small marketing depots (050502). From marketing depots (or directly from border terminals), gasoline is loaded into road vehicles for delivery to service stations where it is transferred into underground storage tanks and subsequently dispensed into automobile fuel tanks. This gasoline distribution chain is presented in Figure 3.1.

Figure 3.1: The gasoline distribution system (0505)



3.2 Definitions

Fixed Roof Tank

A fixed roof tank consists of a cylindrical steel shell topped by a coned roof and could be equipped with internal floating cover in aluminium or steel as well as with a pressure/Vacuum vent (PV vent).

Floating Roof Tank

A tank normally used in terminal operations which is equipped with a roof floating on top of the gasoline.

Marketing Depot

One or more storage tanks where gasoline is received by pipeline, road truck, barge or rail car, and is stored in bulk for subsequent transportation or distribution by road truck.

Onboard Canister

A container filled with an adsorbent (e.g., activated carbon) which collects gasoline vapours in a motor vehicle.

Reid Vapour Pressure (RVP)

The vapour pressure of a product (e.g. gasoline) is determined by a standard laboratory method called RVP, which measures its inherent tendency to evaporate at 38 °C with vapour/liquid ratio of 4/1. RVP is reported in kPa. For details of the equipment and procedures refer to the following standard methods: IP 69/78 (Vapour pressure Reid method), ASTM D323 (Vapour pressure of petroleum products Reid method), ISO 3000-1974 (Petroleum products - Determination of vapour pressure - Reid method).

Service Station

Any premises at which gasoline is dispensed into the fuel tanks of motor vehicles, including marinas (gasoline fuelling point which services water craft) with land-based storage.

Stage I Controls
The equipment used to recover gasoline vapours at terminals (dispatch stations), marketing depots, and from service stations.

Stage II Controls
The equipment used to recover gasoline vapours emitted during motor vehicle refuelling at service stations.

True Vapour Pressure (TVP)
If any liquid is introduced into an evacuated container, molecules will escape from the liquid surface by virtue of their kinetic energy to form vapour. Thereafter, some vapour will condense and eventually a state of equilibrium is reached, which is sustained if the temperature remains constant. The observed pressure in absolute units in the vapour space is defined as the true vapour pressure (TVP) of the liquid at the constant temperature applicable.

Vapour Balancing
Vapours displaced from tanks receiving gasoline are returned to tanks delivering the gasoline.

Vapour Destruction Unit (VDU)
An installation, normally located at a terminal, which receives gasoline vapours from cargo tank trucks and destroys them by thermal oxidation or other means.

Vapour Recovery Unit (VRU)
An installation, normally located at a terminal, which receives gasoline vapours from cargo tanks and recovers them for subsequent use, e.g. condensation.

3.3 Techniques

The refinery products (e.g. gasoline) are stored in tanks of different construction, i.e., fixed or floating roof tanks. Then the products are transferred to tank trucks, rail cars, etc., using various techniques of loading, i.e. top, bottom, or submerged loading. The gasoline is delivered directly to service station (stored in underground tanks) or to marketing depots where it is stored in tanks similar to those used in refineries. In some countries the products are imported and stored at border terminals before distribution (see Fig. 3.1).

Fixed Roof Tank

These tanks are normally equipped with a Pressure/Vacuum vent (PV vent) and can be vapour balanced. They continue to be used for motor gasoline at the smaller installations and depots, typified by lower throughput levels (Williams et al, 1986; ECE, 1990; CCME, 1991). These tanks could be classified as follows (Schürmann, 1994):

- Fixed roof tanks without internal floating roof and without pressure/vacuum (PV) vent;
- Fixed roof tanks with internal floating roof and without PV vent;
- Fixed roof tanks without internal floating roof and with PV valve, whereby pressure range (e.g. +20mbar/-5mbar or +180mbar/-50mbar) has an influence on storage emissions.

The internal floating roofs are typically made of steel or aluminium sheets. The steel internal covers are longitudinally welded and in direct contact with the liquid surface. The aluminium covers generally have a closed surface of clamped sheets and float several centimetres above the product surface on floats (VDI, 1985).

<u>Floating Roof Tank</u>
A tank normally used in terminal operations as well as at principal marketing installations away from refineries. It consists of a cylindrical steel wall equipped with a floating roof. The roof floats on top of the gasoline, and is equipped with seals to the sidewall to minimise vapour loss; the air space above a floating roof is vented to the atmosphere. Floating roof decks are of three general types: pontoons, pan, and double deck. A floating roof tank normally cannot be vapour balanced (Williams et al, 1986; ECE, 1990; CCME, 1991).

<u>Bottom loading</u>
A system for loading liquid petroleum products into a cargo tank truck from the bottom, through a system of pipes, valves and dry-disconnect fittings (CCME, 1991; Williams et al, 1986).

<u>Splash Loading</u>
The loading arm is positioned with the outlet above the tank bottom so that the gasoline falls to the liquid surface. This leads to a high vapour evolution (Williams et al, 1986; ECE, 1990).

<u>Submerged Top Loading</u>
A system for loading liquid petroleum products into any tank by means of a pipe to provide entry below the liquid surface, thereby minimising splash and vapour formation (CCME, 1991; Williams et al, 1986).

<u>Underground Storage Tank</u>
A storage tank that is completely buried by or covered with earth, backfill or concrete, or a partially buried tank. A partially buried tank means a storage tank that has 10% or more of its volume below adjacent ground level. These tanks normally have fixed fill pipes which discharge at the bottom of the tank (CCME, 1991; Williams et al, 1986).

3.4 Emissions

Emissions of hydrocarbons to atmosphere occur in nearly every element of the gasoline distribution chain. The emissions can be classified as follows (for details see Williams et al, 1986 and ECE, 1990):

1. Emissions from bulk storage tanks (refinery dispatch station, border terminals, marketing depots),
2. Service station storage tank emissions;
3. Transport vehicle filling emissions;
4. Other emissions.

3.4.1 Emissions from bulk storage tanks

There are basically two types of bulk storage tanks:

Floating Roof Tanks and Fixed Roof Tanks with internal floating covers

There are two major sources of emissions associated with the storage of intermediate volatility liquids:

a) *Standing storage emissions* are caused mainly by evaporation of liquid product through imperfections in the flexible peripheral seals. Included are any evaporative emissions through the deck structure and fittings such as manholes, gauge pipes and hatches, also roof support columns or legs. The emissions vary depending on design of surface covers (steel or aluminium), see section 3.3. Techniques and 3.5. Controls. Additionally the wind can have a significant influence on the magnitude of these emissions if the tanks are ventilated.

b) *Withdrawal emissions* occur following the withdrawal of liquid product. They are due to evaporation of the film of gasoline which adheres to the surface of the tank walls, and any tank roof support columns fitted. The magnitude of these emissions is mainly influenced by the surface condition e.g., presence of rust or a tank lining.

c) *Filling of the tank* after revisions or complete emptying when the floating roof stands on its supports causes additional emissions.

Fixed Roof Tanks without internal floating covers

a) *Displacement emissions* occur due to displacement of the mixture of air and hydrocarbon vapour by the incoming gasoline. The vapour emitted originates mainly by evaporation from the previous tank contents during storage.

b) *Withdrawal emissions* occur following intake of air via the pressure/vacuum relief valves. Dilution of the hydrocarbon vapour/air mixture previously contained in the vapour space will lead to further evaporation to restore the equilibrium.

c) *Working emissions* are defined as the sum of displacement and withdrawal emissions caused by gasoline movements.

d) *Breathing emissions* are caused by temperature variations and changes in the barometric pressure which in turn cause expansion and contraction of both liquid and vapour within the tank.

3.4.2 Service station storage tank emissions

The main contribution comes from displacement when an incoming bulk delivery of gasoline is received into tanks. There are also withdrawal and breathing emissions, the latter being of minor significance since tanks are normally double walled underground tanks and are not subject to “above-ground” diurnal temperature changes but the variation in atmospheric pressure influences the breathing emissions.

See also note in section 14. Additional Comments on emissions from leaking underground storage tanks.

3.4.3 Transport vehicle filling emissions

These occur when gasoline is transferred from storage tanks into transport vehicles, i.e. road tankers, rail cars, barges, and when dispensed into cars. The emissions are a combination of vapour from the previous tank contents and the vapour evolved as a result of splashing and turbulence during filling. The transit or breathing losses are minor (see section 3.4.4.d). It might be worth paying more attention to vapour emissions resulting from spillage when refuelling cars. Four categories of loss were identified (see below). Most of these losses can be avoided by correct maintenance and handling of the dispensing equipment.

a) Pre-fill drip from the nozzle while being handled between the pump and the vehicle,

b) Spit-back of gasoline from the fuel tank filler pipe, resulting from the pressure build -up in the vapour space,

c) Overflow from the filler pipe,

d) Post-fill drip from the nozzle while being handled between the vehicle and the pump.

3.4.4 Other emissions

Emissions described here are of minor magnitude as compared to those described above and include the following:

a) *Fugitive emissions* occur following seepage of gasoline liquid through parts of handling equipment such as pipeline gaskets, also pump and valve stem seals. Pipelines are closed systems and essentially emission free. They are however subject to some fugitive losses and possible leaks due to temperature rise.

b) *Ship and barge ballasting emissions* - hydrocarbon vapours are displaced into the atmosphere when a compartment, which has previously contained gasoline, is loaded with ballast water.

c) *Transport vehicle emissions whilst travelling* are often negligible because the vapour and pressure retention capability of the tank or compartment will be above the level at which breathing will be induced by the temperature variations that may occur. However, in some cases these emissions should not be neglected; the containers of road vehicles are subject to significant heating up (depending on colour also) whilst the pressure range of their PV vents is limited to 50 mbar, corresponding to a temperature difference of +15ºC, ignoring expansion of liquid. Many rail cars are free vented and their emissions are not negligible.

d) *Spillage and leakage* - any activity involving the transfer of gasoline from one form of container to another is a potential point of spillage. Also, leakage from storage and handling equipment such as loading arms, swivels and storage tanks, in addition to flanges and valves, can contribute to vapour emissions. Such emissions should only make a minimum contribution to the total which occur in the gasoline distribution sector, providing facilities are well designed and operated efficiently.

3.5 Controls

Considerable reduction of hydrocarbon emissions from gasoline distribution network is achieved by modifying truck, barge or rail car tanks loading practices, installing closed vapour recovery units (VRU), as well as providing fixed roof storage tanks with internal floating covers. Additionally, Stage I and Stage II control measures are being introduced. For more details on control options described in this section see Richards et al, 1990; ECE, 1990; Williams et al, 1986; CCME, 1991; VDI, 1985; EPA, 1985.

3.5.1 Storage Tanks

There are several ways to control emissions from storage tanks. In most major terminals, vapour emissions from working tankage are controlled by the use of floating roof tanks or fixed roof tanks with internal floating covers (IFCs). These will reduce vapour emissions from tankage by at least 90% for welded steel pans (VDI, 1985). If aluminium pans are used the reduction efficiency may be lower (ca. 70%). A very simple but effective measure is to paint the shell of tank white. A white coating reflects 70% of the energy of the irradiating sunlight (see VDI, 1985 for more details on effects of different colour and type of coatings). Another option is to install Stage IA devices, described in section 3.5.2. There is an extensive experience in use of internal floating covers and replacement of fixed roof tanks by floating roof tanks. In Finland and Germany the majority of fixed roof tanks are equipped with IFCs. In Canada, in 1983, 89% of this category of tanks were equipped with floating roof (Made, 1988).

Important note:
It is believed that because of the change to unleaded gasoline, the rubber elements, like seals, are deteriorating faster. Therefore, the given reduction efficiencies for storage tanks might not be achieved in some cases (M. Wyser, J. Baumann; pers. communication).

3.5.2 Stage I Controls

Stage I controls refer to a variety of techniques reducing VOC emissions at marketing terminals (Stage IA) and when gasoline is delivered to service stations (Stage IB).

Stage IA
Stage IA systems basically include two parts:

a) *Vapour Balance Lines between Tanks and Loading Gantries* - When a group of fixed-roof gasoline tanks is subject to simultaneous receipts and deliveries, interconnecting the tank vapour spaces can reduce emissions to atmosphere by allowing displaced vapours from a receiving tank to flow into the vapour space of a delivering tank. In some areas vapour return lines have been installed to reduce exposure of vehicle loading personnel to gasoline vapours. Currently, these lines are generally installed in conjunction with a vapour recovery unit (VRU). In Switzerland, all of the marketing depots are fully equipped with vapour balance lines between road tankers and tanks as well as between tanks and tank cars.

b) *Vapour Recovery Units (VRU)* remove hydrocarbons emitted from tanks or vehicle loading operations usually by either cooling/condensation, liquid loading absorption or carbon adsorption or a combination of these processes (for details of the processes see ECE, 1990). The recovered hydrocarbons are usually returned to tankage in liquid form. VRUs are either single-stage, based on one of the above mentioned processes, with recovery efficiencies of the order of 95%, or double-stage, with additional processing of the first stage tail gas, with design efficiencies close to 100%. Until 1988, relatively small number of VRUs had been installed in Europe (Richards et al, 1990) of which the large majority are for road vehicle loading. Recently installed units are designed to meet the US EPA limits of VOC emissions per litre of product loaded into a vehicle, i.e. 35g/m^3 requires single-stage unit, or more stringent TA-Luft limits, i.e. 150 mg/m^3 requiring double-stage VRUs. In Switzerland, VRUs are installed at border terminals and refineries.

Richards et. al, 1990 gives average efficiencies of Stage IA systems, assuming 95% efficiency of VRU, 95% vapour collection efficiency at the loading gantry for bottom loading and 85% for top loading, as 90% and 80%, respectively. These numbers are based on an average TVP of 35 kPa. Schürmann, 1994 uses different efficiencies, namely 100% for bottom loading and 85% for top loading with gas balancing systems.

Stage IB

Stage IB applies to vapour balancing systems between service station tanks and trucks supplying gasoline to them. Saturated vapours, displaced from the tank vent pipes when receiving gasoline, are returned to the truck compartment from which the gasoline is supplied, via a piping system and/or hoses. There are several piping configurations possible, for details see Richards et. al, 1990, ECE, 1990, Williams et al, 1986. According to CONCAWE (Richards et. al, 1990) about 33% of service stations in EC12 countries in 1988 were equipped with Stage IB systems. It has been reported that with well designed systems vapour collection efficiencies are higher than 95%. Schürmann, 1994 uses in his report a reduction efficiency of 100% for stations equipped with Stage IB controls.

3.5.3 Tank Trucks

To reduce emissions, modified loading techniques are recommend, namely:

a) Submerged top loading (reduces VOC emissions by 40 to 60%),
b) Submerged top loading with in-line vapour return,
c) Submerged top loading with external vapour return,
d) Bottom loading,
e) Bottom loading with vapour return .

Vapour collection and return from service stations is only undertaken in five European countries and both top and bottom loading trucks are equipped there with vapour return systems. In the USA, bottom loading with vapour return has been legally enforced by EPA standards since 1982. A typical emission reduction efficiency for vapour recovery at tank truck loading points given by OECD, EEC and CONCAWE is 89%. But there are several units installed in Germany to meet stringent regulations and their efficiency is 99.9% (ECE, 1990). This is also reported for Switzerland (Schürmann, 1994; M.Wyser pers. comm.).

3.5.4 Rail Cars

Rail cars are generally top loaded in Europe. The recommended techniques to reduce emissions are the same as for tank trucks (see 3.5.3). According to OECD, EEC, and CONCAWE, vapour recovery units are operating with an average efficiency of 89% at rail car loading points (ECE, 1990). Schürmann, 1994 reports 85% efficiency for top loading operations with gas balancing systems. This efficiency could be improved if bottom loading would be introduced on a wider scale. Its introduction would additionally require automatic overfill protection systems on all rail cars.

3.5.5 Barges/Ships

Modified loading techniques reduce loading losses by 60 to 80%. This involves low initial loading to reduce turbulence when filling the bottom, fast bulk (bottom) loading and slow final loading to reduce turbulence in the vicinity of the ullage as the liquid approaches the top (ECE, 1990). Vapour return/recovery systems are not very common. For inland barges equipped with such systems efficiencies of 88% and for ocean ships of 89% are reported by the EEC (Bouscaren et. al, 1988). Sometimes, the controls are installed but not used, according to M. Wyser (pers. communication) inland tankers on the Rhine river are equipped with vapour balancing systems but the systems are not used.

3.5.6 Car Refuelling

Stage II Controls

Stage II applies to vapour balancing systems between automobile fuel tanks during refuelling and the service station tank supplying the gasoline. Saturated vapours are displaced from the automobile fuel tank and returned to the service station tank via special fittings in the dispensing nozzle. Vapour escape from the automobile fill-pipe to the atmosphere is prevented by a special bellows which seals the fill pipe and routes the displaced vapours through the body of the dispensing nozzle to the hose. Different systems are available, in some of which the vapour flow is boosted by a vacuum pump. Essential to this system are standardised fill pipes and existence of Stage IB controls in place, otherwise Stage II devices may only delay the venting of vapour to the atmosphere.

In the late 80’s, comprehensive test programmes were carried out in Sweden and Switzerland to estimate the recovery efficiency applying Stage II controls. The recovery efficiency of the system, weighted to the Swedish car population, was determined to be 56% and for Switzerland 53% (Switzerland has decided in 1989 to introduce Stage I and II controls at all service stations and vapour recovery at the principal storage units by 1994). Similar results were achieved in an investigation of the BP oil company at one of its stations in Stockholm. The recovery efficiency varied from 11 to 89%, average 61%, depending on the car type. To achieve a better efficiency, it will be necessary to introduce modifications to all new European car fill-pipes and tank vents. In the absence of these changes, an average efficiency between 50 and 60% can be assumed (Richards et. al, 1990). In the USA, where standardisation has been introduced, the EPA estimates the average in-service efficiencies at 62 to 86%, depending on the level of regulatory enforcement, mainly regular inspection. Additional problems with Stage II equipment, mentioned in the literature, are that this system cannot be used with shallow fuel tanks (motorcycles) and that American experience indicates greater spillage when these systems are installed.

On-board Canisters

These are a viable alternative to Stage II controls. According to the experience in the USA and CONCAWE (McArragher et al, 1988), enlarged carbon canisters could reduce refuelling emissions by more than 95%. Canisters are filled with activated carbon to which all external fuel system vents are connected. Any diurnal, hot soak as well as refuelling hydrocarbon emissions are adsorbed by the carbon and retained in the canister. The carbon is purged of hydrocarbons during normal driving by drawing the air back through the canister and into the engine where it is burnt.

RVP Reduction

This control option requires the reduction of gasoline volatility at the refinery from May to September. A reduction of volatility (RVP) of 17 kPa (from 79 to 62 kPa) would result in a 8 to 10% reduction of the annual emissions of VOC from the gasoline distribution sector (Environment Canada, 1989). Gasoline volatility reduction is reported to reduce VOC emissions from refuelling by 23% (ECE, 1990).

4 SIMPLER METHODOLOGY

The simpler methodology is based on aggregated average emission factors (see section 8.1) combined with information on pumped volume of gasoline in the country. Where the information on type, efficiency and extent of emission control measures applied in distinguished sectors is available, the detailed methodology should be used.

Emission = (Average emission factor, see Table 8.1) x *(pumped volume of gasoline)*

This simpler approach has been applied by CONCAWE to estimate emissions of VOC from the gasoline distribution sector in Western Europe (Edwards et. al, 1986). Similar average emission factors for the elements of gasoline distribution system are also given (with some reservations - see Veldt et. al, 1992) in the Second Edition of the CORINAIR Inventory Default Emission Factors Handbook (Bouscaren, 1992).

5 DETAILED METHODOLOGY

To improve the quality of emission estimates, country specific data should be taken into account. Therefore, the detailed methodology requires knowledge on specific parameters of the gasoline distribution system (see section 6 below). Additionally basic physical and chemical parameters of distributed gasoline should be known. For details see procedure described in reference studies i.e., Williams et al, 1986; Foster et al, 1987; VDI, 1985.

An alternative methodology was offered by Swiss BUWAL (Bundesamt für Umwelt, Wald und Landschaft) (Schürmann, 1994). The following paragraph gives a general description of the methodology and is quoted after Schürmann, 1994.

The proposed detailed methodology is based on the analysis of gasoline flows from imports and refineries to car filling stations and the various loading and unloading techniques used. From the gasoline flow, a gas flow model is derived, which is analysed with regard to gas handling techniques to give distribution emissions on one hand and on determination of storage emissions on the other hand. It involves the following steps:

a) Determination of the gasoline flows (in Mg/a) from the product sources (refineries and imports) to the filling stations.
b) Determination of the gas flows (in m^3/a) from the gas source (car) to the various emission locations or emission control locations
c) Determination of the VOC-emissions for gasoline distribution (in kg/a)
d) Determination of the VOC-emissions for gasoline storage (in kg/a)

This methodology has the following advantages:

- It reflects the actual emission situation better than aggregated emission factors,
- The results reflect directly the percentage of introduction of gas handling control measures (e.g. stage I and stage II) and of VRU installations in terminals,
- The emission factors for the various emission sources can be adapted to the local properties of gasoline composition, to the level of introduction of integral gas balancing techniques etc.,
- The detailed methodology is a model calculation which allows an analysis of the efficiency of various control measures and as such is an instrument for the planning of the introduction of control techniques.

The current version of this methodology is being reviewed, extended and tested by Swiss BUWAL. An up-to-date version, description and the diskette may be ordered from Dr. Jürg Baumann, BUWAL, Laupenstr. 20, 3003 Bern, Switzerland.

The following sections in this chapter of the guidebook do not refer to the ‘Swiss’ methodology since it was not available at the time of writing.

6 RELEVANT ACTIVITY STATISTICS

6.1 Simpler methodology

To estimate VOC emissions from the gasoline distribution sector (0505) the statistics of gasoline sold in the country/region are required. For calculation of emissions resulting from activities in relevant subsectors of gasoline distribution, distinguished in CORINAIR, emission factors given in section 8.1 of this document are used.

To take into account emission control measures in place, necessary data may be available from sectoral statistics or country studies. The reduction efficiencies given in section 3.5 of this document could be applied or (preferably) the efficiencies reported in national studies should be used. However, it is considered that where information on controls is available the detailed methodology described below or the ‘Swiss’ method should be used.

6.2 Detailed methodology

More detailed country specific data are needed as far as the technical parameters of equipment as well as operation practices are concerned. This includes:

a) *Refinery Dispatch Station (050501)* - number, type, size of the tanks used at the refinery dispatch station as well as volume of gasoline stored in these tanks; volume of gasoline loaded into different transport modes (e.g., rail truck, pipeline, tank truck); gasoline loading practices for specific modes of transport (e.g., top-submerged, bottom); type and extent of emission control measures in place (e.g., Stage I).

b) *Transport and Depots (050502) and Border Terminal, where applicable* - number, type, size of the tanks used as well as volume of gasoline stored in these tanks; gasoline loading practices for used transport modes; type and extent of emission control measures in place (e.g., Stage I).

c) *Service Stations (050503)* - volume of gasoline sold; type and extent of emission control measures in place (e.g., Stage II , percentage of cars equipped with enlarged carbon canisters, the latter not relevant for past year inventories as this technology is not yet in use).

d) *Characteristics of distributed gasoline* - RVP, TVP, density.

Additionally, some meteorological data like average annual (or seasonal) temperature are needed to improve the quality of the inventory or calculate the seasonal variation in emissions.

7 POINT SOURCE CRITERIA

Not applicable - see section 12.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

The emission factors presented are derived from the study of CONCAWE (Williams et al, 1986). The assumed liquid gasoline density is 730 kg/m^3 and condensed vapour density is 600 kg/m^3. Hydrocarbon emission factors for uncontrolled techniques are given in Table 8.1.

Table 8.1: NMVOC emission factors [g NMVOC/Mg of total gasoline handled]

Category	Emission factor	Quality code
Refinery Dispatch Station (050501)	310	D
Transport and Depots (050502)	740	D
Service Station (050503)	2880	D
Gasoline Distribution (0505)	3930	D

Information provided in CORINAIR'90 database suggests that many experts used very similar average emission factors for considered sectors. Average emission factors used for 050501 vary from 200 to 500 g/Mg, for 050502 from about 600 to as much as 3120 g/Mg (in Germany), and for 050503 from 2000 to 4500 g/Mg. The information on gasoline and vapour density is not provided in CORINAIR database. The values provided in the Table 8.1 are also confirmed by Czech estimates provided by Mr. B. Bretschneider (pers. comm.), based on the Czech emission inventory system REZZO. The emission factors estimated at different gasoline terminals (050502) vary from about 300 to nearly 1500 g/Mg with an average of 800 g/Mg of gasoline. For the service stations REZZO suggests emission factors from about 1500 to 2500 g/Mg with an average 1660 g/Mg of gasoline, it is not clear though if the emissions from loading of the tanks at the service stations are included in this estimate, i.e. it might represent emissions from car refuelling and spillage only.

8.2 Detailed Methodology

The emission factors given in this section are derived from the CONCAWE studies (see Williams et al, 1986; Foster et al, 1987) assuming the following typical European gasoline properties:

true vapour pressure (TVP)	35 kPa
liquid molecular weight	64 kg/kmol
condensed vapour density	600 kg/m^3
liquid gasoline density	730 kg/m^3

Additionally, emission factors reported in the ECE, 1990 study are given in brackets. They are, in general, based on experience of the United States Environment Protection Agency (US EPA).

8.2.1 Refinery Dispatch Station (050501)

It is assumed that there are only external floating roof (EFR) tanks in use at the refineries. They are equipped with mechanical shoe primary seal (see section 3.3.3.1. in Williams et al, 1986). Storage tank emissions are the sum of standing storage and withdrawal emissions.

The emission factors for ship/barge loading operations are weighted averages of conditions specified in the CONCAWE report (Williams et al, 1986). Where detailed data on the prior cargo and compartment treatment for the previous empty or ballasted voyage are available, emission factors specified in section 3.3.4.5 in Williams et al., 1986 should be used. In brackets emission factors reported in ECE, 1990 are given.

One of the parameters, used to evaluate emission factors for rail/truck tank loading operation, represents the amount of splashing. Its value depends on loading practice as well as the arm outlet height from the bottom of compartment. Some typical values estimated by BP, 1973 were used. Where detailed data exist, the values and the formulas given in section 3.3.4.3 and 3.3.4.4. in Williams et al, 1986 should be used.

Table 8.2: NMVOC emission factors (uncontrolled) for Refinery Dispatch Station (050501) [g NMVOC / Mg gasoline throughput]

Category	**Emission factor** [1) 2)]	**Quality code**
Storage tank emissions (EFR)	26	D
Loading		
Pipeline	0	C
Ship/ocean barge	300 (430)	C
Shallow draft barge	560 (640)	C
Rail cars		
Top-submerged	500 (800)	C
Top-partial splashing	1060 (2000)	D
Road trucks:		
Splash loading	(2050)	E
Top - partial splashing	870	D
Top - submerged	450 (670)	C
Bottom	410 (670)	C

1) reported emission factors are based on Williams et al., 1986

2) emission factors in brackets are based on ECE, 1990.

8.2.2 Transport and Depots and Border Terminals (050502)

The breathing emissions during transport of gasoline from the refinery to the marketing depots or service stations are not significant, they are assumed to be less than 0.001% liquid volume (see Williams et al, 1986). Ballasting emissions depend on intake of ballast water after a gasoline cargo discharge. In table 8.3, intake of water is expressed as percent volume of gasoline discharged. In the study by ECE, 1990 an average emission factor, based on US EPA experience, is given in brackets. For external floating roof (EFR) and internal floating cover (IFC) tanks, storage emissions are the sum of standing storage and withdrawal emissions. Fixed roof tanks storage emissions are the sum of working and breathing emissions (see section 3.4 of this document).

Where Border Terminals are equipped with storage tanks comparable to the tanks in the refinery and other modes of transport than road trucks are used, coefficients from table 8.2 should be applied accordingly.

Table 8.3: NMVOC emission factors (uncontrolled) for gasoline - Transport and Depots [g NMVOC/ Mg gasoline throughput]

Category	Emission factor [1] [2]	Quality code
Transport from refinery	< 8	C
Ballasting (ships/barges)		
water intake - 100%	220	C
water intake - 30%	66	C
ECE, 1990	140	D
Storage tank emissions		
EFR - primary seal	73	D
EFR - secondary seal	5	D
IFC	160	D
Fixed roof	1570	E
Loading - road trucks		
Splash Loading	(2050)	E
Top - partial splashing	870	D
Top - submerged	450 (670)	C
Bottom	410 (670)	C
Other		
Fugitive	< 8	C
Spillage	80	C
Transport to service stations	< 8	C

[1] reported emission factors are based on Williams et al., 1986

[2] emission factors in brackets are based on ECE, 1990.

8.2.3 Service Stations (including refuelling of cars) (050503)

Emission factors reported here are derived from CONCAWE study (Williams et al, 1986) and from the report by ECE, 1990 (given in brackets).

Table 8.4: NMVOC emission factors (uncontrolled) for Service Stations (050503) [g NMVOC / Mg gasoline throughput]

Category	**Emission factor [1] [2]**	**Quality code**
Filling/Storage		
Submerged loading	1315 (1400)	C
Splash loading	(2050)	C
Car filling	1480 (1800)	C
Spillage	80 (110)	C

[1] reported emission factors are based on Williams et al., 1986

[2] emission factors in brackets are based on ECE, 1990.

9 SPECIES PROFILES

Measurements of hydrocarbon composition in the gasoline distribution system are fairly consistent, reflecting the fact that one deals with a single product of relatively constant composition. Thus, measurements taken at tank vents, and downwind from the terminal in unrelated locations give generally the same results. Limited data on emissions from service stations are consistent with the known composition of emissions from terminals handling gasoline (Edwards, et. al, 1986). These data are presented in Table 9.1. The last column in this table shows composition of gasoline vapours from petroleum industry (adapted from Veldt et. al, 1992). The data are averages derived from literature review of measurement experience in many countries (to large extent US - for details see EPA, 1990). According to Veldt et. al, 1992, the composition of gasoline vapour is highly variable depending on liquid composition (e.g., summer and winter blend) as well as on the evaporation process (temperature and time). However, aggregating species to groups as in Table 9.1 shows quite a good agreement of composition derived from both studies.

Table 9.1: VOC profiles of gasoline terminal air samples (Edwards et. al, 1986) and of petroleum industry emissions of gasoline vapour (Veldt et. al, 1992) [wt. %]

Substance	Tank vent	Downwind	Petroleum ind.
Alkanes			
Ethane	-	-	-
Propane	-	2.0	1.0 (0.2 - 2)
C_4+	89.2	89.1	85.0 (>45)
Alkenes			
Ethene	-	-	-
C_3+	6.9	6.5	11.0 (>5.5)
Aromatics			
Benzene	1.1	1.5	1.0 (0.5 - 2)
Toluene	2.0	0.9	1.5 (0.5 - 3)
Xylene	0.8	-	0.5 (0.1 - 1)
TOTAL	100.0	100.0	100.0

10 UNCERTAINTY ESTIMATES

In this chapter, the methodology to calculate the emissions from gasoline distribution system as well as from storage of gasoline in the refinery dispatch station is described. However, chapter 040104 ‘Storage and Handling of Petroleum Products in a Refinery’ in this guidebook covers the latter source. Therefore, there is a danger of double counting especially in case when the simplified methodology is used and consequently aggregated emission factors are used. There is a need to discuss this issue and possibly modify the SNAP code, i.e. exclude, for example, emissions from refinery dispatch station from this subsection or replace it by border terminal stations (where applicable) and then the gasoline distribution system would only include gasoline flow outside the refinery.

11 WEAKEST ASPECTS / PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The methodology presented in this chapter is based on hypothetical, representative for Western Europe distribution network but it may not reflect real situation (system configuration) in a particular region or country (compare remarks in section 8 on emission factors used in CORINAIR inventory). Therefore, measurement campaigns carried out by independent groups of experts as well as comparison of emission factors with other countries could provide a valuable input to the continuous improvement of emission estimation technique.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Where no detailed information is available on location and throughputs of considered elements of the gasoline distribution network, the emissions from service stations (050503) should be distributed evenly across regions (e.g., administrative units) or grids or based on population data. The same applies to emissions from sub-sector (050502) if the appropriate data are not available although the location and throughput of principal marketing depots as well as border terminals should be known. The location of refineries is usually known (in many countries there are few, if not only one). Therefore, emissions from refinery dispatch stations (050501) can be attributed to a particular region or grid.

13 TEMPORAL DISAGGREGATION CRITERIA

The true vapour pressure (TVP) of gasoline is influenced by its temperature and reid vapour pressure (RVP). It is possible, using equations given in Williams et al, 1986, to calculate emissions, resulting from storage and loading operations, from gasoline distribution sector, including data on gasoline properties (e.g., RVP) and average annual or monthly temperature.

An experimental work carried out by Deutsche Gesellschaft für Mineralölwissenschaft und Kohlechemie (DGMK, 1976) showed a seasonal variation, in filling/storage emissions from service stations, of 0.145/0.125% mass which occurred in summer/winter, respectively.

14 ADDITIONAL COMMENTS

Recently, US EPA has contracted Radian Corporation to develop the methodology to estimate VOC emissions from leaking underground storage tanks (LUST) (R.Ryan, US EPA, pers. communication). LUST are typically not considered a quantifiable source of air emissions until excavation and remediation efforts are initiated. In many cases, the leaking tank and surrounding soil are removed and either placed in piles or evenly spread to allow volatilisation of the contaminant. It is a common practice, especially where the contaminant is highly volatile, like for example gasoline. This note is only to inform about such activity as the final results are not yet available. It is believed that this source of emissions might contribute to local ozone episodes.

To forecast the emissions of VOC from a gasoline distribution system the forecast of gasoline demand is necessary as well as the extent and type of control options introduced. There are usually several energy forecasts available but it is more difficult to find information on possible technical development as well as plans for introducing particular controls. In this case, the emission development scenario could be based on energy forecast and on known current and forthcoming emission regulations, and on current national or international agreements on emission reductions.

15 SUPPLEMENTARY DOCUMENTS

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16 VERIFICATION PROCEDURES

The emission factors presented in this chapter are not necessarily representative for a particular region/country due to substantial differences in handling practices, product properties as well as meteorological conditions. The verification can be based on local measurements or measurements performed for similar conditions.

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODES :

050600
050601
050603
010506

SOURCE ACTIVITY TITLES :

Gas Distribution Networks
Pipelines
Distribution Networks
Pipeline Compressors

1 ACTIVITIES INCLUDED

This chapter considers emissions from the transmission of gaseous fossil fuel from terminals to consumers via pipelines, compressor stations and networks. Most of the information in this chapter is based on data for natural gas.

Emissions from gas terminals are covered in the chapter on Extraction and first treatment of liquid and gaseous fuels (50200/50300).

2 CONTRIBUTION TO TOTAL EMISSIONS

Methane and NMVOCs are the pollutants that are likely to be emitted from gas distribution networks in significant quantities.

Table 2.1 refers to the UK only and to the year 1992. Data are from the UK Digest of Environmental Protection & Water Statistics 1994. The NMVOC component of natural gas was calculated using the UK species profile given in Section 9.

Table 2.1 - UK emissions from gas distribution networks (1992)

	Methane	**NMVOC**	**Total**
Emission due to natural gas leakage (kt)	375	42	417
Total emission (kt)	4736	2556	7292
Natural gas leakage as % of total emission	7.9	1.6	5.7

Table 2.2: Contribution to total emissions of the CORINAIR90 inventory *(up to 28 countries)*

Source-activity	**SNAP-code**	**Contribution to total emissions [%], (including emissions from nature)**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Gas distribution networks	**050600**			**0.5**	**6.0**				

0 = emissions are reported, but the exact value is below the rounding limit of 0.1 per cent
- = no emissions are reported

3 GENERAL

3.1 Description

Natural gas is a combustible gas that occurs in porous rock of the earth's crust and is often found with or near accumulations of crude oil. It may also occur alone in separate reservoirs. Gas wells exist on land and offshore. Some countries may also use gas derived from coal. Coal gasification has been practised since the early nineteenth century and can be done using a number of different processes.

The main use of natural gas is heating buildings and processes and as a chemical feedstock, for example in the manufacture of ammonia and fertilisers. Also, it is increasingly being used as a fuel for power generation.

Natural gas is transferred from the well to a processing plant where it is separated by cryogenic distillation to give 'sales' gas of the required specification as well as possibly other products such as liquid hydrocarbon fractions. After this it is transferred via a network of pipelines and networks or 'mains' to consumers ranging from large factories to small dwellings. Natural gas may also be transported in liquefied form by ship, in which case it is loaded and unloaded at specially designed marine terminals.

A gas transmission network covering a country or region consists of pipelines and mains of a variety of different sizes, materials, and pressures. It will also contain storage facilities, pumping stations and pressure reduction stations. Pipes will also make use of different types of joint.

Transmission systems

Gas transmission systems can conveniently be divided into two interconnecting systems; the national transmission system, which consists of large diameter high pressure pipelines spanning distances of hundreds of kilometres, forms the backbone of the network and takes gas from the terminals to each of many regional supply systems, which consist of smaller diameter intermediate and low pressure pipelines and mains.

Pipelines & mains

Pipelines and mains are made from the following materials:

- Welded steel
- Cast Iron
- Ductile Iron
- Polyethylene

Pipelines and mains are operated under a variety of different pressure regimes, usually classified as follows:

- High pressure - up to 75 bar
- Intermediate pressure - 2 to 7 bar
- Medium pressure - 2 bar to 75 mbar
- Low pressure - < 75 mbar

Service pipes, which transfer gas from a main to a customer's meter, are always at low pressure.

Pipelines and mains can also be classified as jointed or unjointed. Jointed pipes have joints which consist of flanges bolted together or similar arrangements. In unjointed pipes the sections are welded together.

Storage

The gas transmission system incorporates a number of different types of storage elements. These include high pressure liquid storage, underground salt cavities and gas holders.

Losses

Losses can occur in many different ways from the network. For example, losses due to leakage and losses due to the purging of sections of pipe and items of equipment during commissioning, decommissioning and maintenance. Leakage can be further classified according to whether it is due to some malfunction, such as a crack in a pipe or a failure of a joint, or whether it occurs in fully functioning equipment as a direct consequence of its design and operation.

Emissions from gas transmission networks arise from a large number of small sources spread over a large area (fugitive). It is estimated that up to 20% of the gas escaping from leaky pipelines and mains is oxidised in the soil by micro-organisms.

3.2 Definitions

Compressor stations

These are pumping stations designed to either raise or maintain the pressure in the pipeline or main.

Distribution System

The term ‘distribution’ usually refers to the low pressure part of a country’s gas supply network rather than describing the system as a whole.

High pressure LNG storage

Large vessels in which natural gas is stored in liquid form under pressure.

Mains

Transmission pipes on a local level. Typically the sort of gas pipes found under the streets. Classified as low, medium or intermediate pressure.

Pipeline

The term pipeline is generally restricted to the large diameter, high pressure pipes used in national transmission systems and the high pressure parts of regional transmission systems. The smaller pipes branching off from these are referred to as mains.

Ports

A facility at which liquid natural gas is loaded onto and off ships.

Service mains

Also referred to as service pipes or ‘services’. These are the narrow, low pressure pipes leading directly to a customers premises.

STP

Standard Temperature & Pressure - refers to a temperature of 373.15 K and a pressure of 101325 Pa.

Terminals

A facility for storing and processing gas at the end of a pipeline from a well. The well can be either on shore or offshore.

3.3 Techniques

The technology which forms part of a typical gas transmission network is described in Sections 3.1, Description, and 3.2, Definitions, above.

3.4 Emissions

The pollutants emitted by the various parts of a typical gas transmission network are described in Section 9, Species Profiles, below and the various emission sources within a gas transmission network are described in Sections 3.1, Description, and 3.2, Definitions, above. As mentioned in Section 3.1 above it is estimated that up to 20% of the gas escaping from leaky pipelines and mains is oxidised in the soil by micro-organisms. However, since it is not possible to measure how much of the gas gets oxidised in this way it is recommended that this phenomenon is ignored in the estimation of emissions.

3.5 Controls

End of pipe techniques are inapplicable because the emissions cannot be collected together in a pipe or duct, instead they arise from a geographically diverse array of small sources emitting directly to the atmosphere. Consequently the only way is to reduce emissions by:

- the use of better materials for pipes, joints and seals
- the quicker detection and rectification of leaks
- improved maintenance
- measures to collect gas purged during commissioning, decommissioning & other maintenance activities

4 SIMPLER METHODOLOGY

In the absence of data characterising the transmission network, an emission can be estimated from the total sales of gas in the region or country. Emission factors can be expressed either as a percentage of total gas sales in tonnes or using an emission factor in tonnes per PJ of energy.

5 DETAILED METHODOLOGY

The detailed methodology requires much greater information on the gas transmission system. This information is normally available from the distribution company.

The first step is to divide the pipeline network of the country into categories. The categories should be chosen so that data on the installed length (i.e. number of km) of each category of pipeline is available and also so that pipelines in each category have common emission characteristics. Table 5.1 lists a suggested scheme of pipeline categories and Table lists a suggested scheme of point sources.

Equation 1 is a calculation to estimate the emission. It refers to m different categories of pipeline and p categories of point source, e.g. gas holders, compressor stations etc. In the rest of this document m = 7 and p = 3. However, these numbers may differ for different countries according to the choice of categories of pipeline and point source. Examples of the allocation of suffixes in equation 1 are shown in Table 5.1 and Table 5.2.

$$E = \sum_{i=1}^{m} l_i p_i f_i + \sum_{k=1}^{p} n_k F_k \qquad (1)$$

Where: l_i = the length, in km, of pipeline of type i

p_i = the pressure, in mbar, of the gas in pipeline of type i

f_i = an emission factor, in tonnes per year per km per mbar

n_i = number of point sources of category i

F_i = leak rate in tonnes per year

Table 5.1 - Pipeline Types

Suffix	Pipeline Category
1	high pressure pipeline
2	jointed low pressure and service mains
3	unjointed low pressure and service mains
4	jointed medium pressure mains
5	unjointed medium pressure mains
6	jointed intermediate pressure mains
7	unjointed intermediate pressure mains

Table 5.2 - Point Sources

Suffix	Point Source
1	high pressure LNG storage facilities
2	compressor stations
3	gas holders

6 RELEVANT ACTIVITY STATISTICS

For the simpler method, only the energy value of the gas consumed is required.

For the detailed method, the activity statistics that appear in equation 1 are needed.

For breaking down the emission into individual compounds the local composition of the natural gas is also required.

7 POINT SOURCE CRITERIA

Storage facilities and processing plants should always be treated as point sources.

Compressor stations may be treated as point sources if sufficient data are available.

Further geographical disaggregation is discussed in Section 12 below.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Method

Table 0.1: Default Emission Factors for Simpler Method

Compound	**Emission factor** (tonnes per PJ of energy)	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference**
Methane	14.8 - 27	E	NA	NA	NA	Western Europe	4
Total emission	19 - 35	E	NA	NA	NA		†
Methane	39.6 - 104	E	NA	NA	NA	US & Canada	4
Total emission	51 - 130	E		NA	NA		†
Methane	218 - 568	E	NA	NA	NA	Former USSR, Central & Eastern Europe	4
Total emission	280 - 730	E	NA	NA	NA		†
Methane	40 - 96	E	NA	NA	NA	Other Oil Exporting Countries	4
Total emission	51 - 120	E	NA	NA	NA		†
Methane	40 - 96	E	NA	NA	NA	Rest of World	4
Total emission	51 - 120	E	NA	NA	NA		†

† derived from methane figures by assuming that the gas is 78 wt% methane

Error limits: ± >100% of emission estimate.

8.2 Detailed Method

8.2.1 High pressure storage facilities, F_2

The preferred way to estimate the emission factor is to carry out ambient concentration measurements and calculate the source strength from these. Alternatively a component-emission factor may be used. If this method is used the error limits on the emission factor will be ± 10% of the emission factor.

There is currently no default emission factor to propose for this source

8.2.2 Compressor station, F_3

Determine by ambient concentration measurements as for 8.2.1 above. If this method is used the error limits on the emission factor will be ± 10% of the emission factor
Default emission factor: 71.5 t/y (from reference 1)

8.2.3 Gas holder, F_4

This can be determined by isolating a gas holder and measuring its loss in height over a given time period. If this method is used the error limits on the emission factor will be ± 100% of the emission factor

Default emission factor: 4 t/y (from reference 1)

8.2.4 High pressure pipeline, f_1

Only determine if the high pressure pipeline system is old and considered to be leaky. Emission factors can be estimated by carrying out pressure decay experiments on isolated sections of pipeline. The technique for doing this is described in Section 16.1. If this method is used the error limits on the emission factor will be ± 10% of the emission factor.

Default emission factor: 0 t/y (from reference 1)

8.2.5 Medium & intermediate pressure pipeline & main, f_4, f_5, f_6 & f_7.

Determine by pressure decay experiments on isolated sections of pipe as described in Section 16.1.

Default emission factors 0.04 m^3/km/mbar/year for jointed pipes and 0.00004 m^3/km/mbar/year for unjointed pipes. Calculate tonnages using the ideal gas equation and the average molecular weight of the gas determined from its composition (from reference 1).

8.2.6 Low pressure main & service pipes f_2, f_3.

Determine by pressure decay experiments on isolated sections of pipe. This should be carried out as described in Section 16.1.

Table 0.2: Default Emission Factors for Detailed Method

Compound	Source	Symbol	Value	Unit	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference
methane	high pressure storage facilities	F_2	no data	t/y	E	NA	NA	NA	UK	1
methane	high pressure pipeline	f_1	0	t/y/km	E	NA	NA	NA	UK	1
methane	jointed intermediate pressure main	f_6	0.04	m^3/km/m bar/year	E	NA	NA	NA	UK	1
methane	unjointed intermediate pressure main	f_7	0.00004	m^3/km/m bar/year	E	NA	NA	NA	UK	1
methane	jointed medium pressure main	f_4	0.04	m^3/km/m bar/year	E	NA	NA	NA	UK	1
methane	unjointed medium pressure main	f_5	0.00004	m^3/km/m bar/year	E	NA	NA	NA	UK	1
methane	jointed low pressure main & service pipes	f_2	88	m^3/km/year/mbar	E	NA	NA	NA	UK	2
methane	unjointed low pressure main & service pipes	f_3	88	m^3/km/year/mbar	E	NA	NA	NA	UK	2
methane	compressor station	F_3	71.5	t/y	E	NA	NA	NA	UK	1
methane	gas holder	F_4	4	t/y	E	NA	NA	NA	UK	1

9 SPECIES PROFILES

Species profiles can be estimated by assuming that the composition of the emission is the same as the composition of the gas, although in practice for some types of emission, e.g. leaks from underground pipes, some components of the gas may get adsorbed, e.g. by the soil. However, we recommend that these effects are ignored because they cannot be quantified. Table 9.1 lists typical species profiles for a number of countries:

Table 9.1: Typical species profiles for emissions from gas distribution networks

	UK*	Netherlands†	Germany††	France††
Carbon Dioxide(CO_2)	0.5	5.0	2.2	0.9
Nitrogen(N_2)	2.5	6.1	7.6	4.5
Methane(CH_4)	92.5	84.7	85.5	88.6
Ethane(C_2H_6)	2.9	3.8	3.3	4.7
Propane(C_3H_8)	0.9	0	0.9	0.8
2-methylpropane (C_4H_{10})	0.2	0.1	0	0
Butane(C_4H_{10})	0.2	0.1	0.4	0.2
2,2-dimethylpropane(C_5H_{10})	0.1	0	0	0
2-methylbutane(C_5H_{12})	0.1	0.1	0	0
Pentane(C_5H_{12})	0.1	0.0	0.1	0.3
Hydrogen Sulphide (H_2S)	0	0.1	0	0
Total mole %	100	100	100	100

* reference 5
† reference 6
†† reference 7

The data in Table 9.1 are mole percentages.

The following default profile has been derived from the above profiles by taking the average and rounding to the nearest whole percent:

Table 9.2: Default species profile for emissions from gas distribution networks

	mole %	**wt %**
Carbon Dioxide(CO_2)	2	5
Nitrogen(N_2)	5	8
Methane(CH_4)	88	78
Ethane(C_2H_6)	4	7
Propane(C_3H_8)	1	2

In the absence of any other data this profile should be used.

10 UNCERTAINTY ESTIMATES

10.1 Simpler method

For the simpler method the only available way of estimating the degree of uncertainty is by intuition based on experience. The uncertainty limits for the estimates derived using the simpler method are about a factor of 2.

10.2 Detailed method

The detailed method requires the determination of emission factors for various sources within the gas transmission network and the error in the final emission estimate will depend on the way in which these factors are determined. Section 8.2, suggests error limits for each of the methods discussed. However, in practice the error limits may differ from these if the techniques used to estimate the emission factors are not identical to those described in Section 8.2. Section 8.2 also gives error limits for the default emission factors.

The error limits for the emission factors should be combined with the error limits for the activity statistics (which should be available from the source of the statistics) according to the usual rules of the propagation of errors to give an error limit for the total emission.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHOD

11.1 Simpler method

This method depends on the default emission factor. However, better estimates of the emission factor can only be obtained by using the detailed method.

11.2 Detailed method

The main weakness of the detailed method is that it can be quite effort intensive to determine accurate emission factors.

12 SPATIAL DISAGGREGATION

The gas transmission system can be divided into two, the two parts being the national transmission system consisting of a relatively small number of high pressure pipelines covering distances of hundreds of kilometres, the second part being the rest of the transmission system. Data on the locations of the various pipelines which form the national transmission system should be readily available for most countries. These can then be regarded as line sources. Emissions from the rest of the system can be broken down into a mixture of area sources, proportional to population density, and point sources corresponding to the locations of major installations such as terminals, storage, processing plants and larger compressor stations.

13 TEMPORAL DISAGGREGATION CRITERIA

Leakage rate is a function of pressure rather than throughput. It is therefore safe to assume that the leakage rate is constant.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents are required.

16 VERIFICATION PROCEDURES

The emission factors for the detailed method can be checked by carrying out pipeline leak tests as described in Section 16.1.

16.1 Pipeline Leak Tests

Identify a representative sample of pipes to test. The best way of doing this is to compile a table such as the figure below dividing up the national network into a number of categories based on pipe diameter and material:

Table 16.1: Example table for pipeline leak tests

Diameter	Steel	Pit Cast	Spun Cast	Ductile	PE
≤8cm					
10-13cm					
15-18cm					
20-28cm					
≥30cm					

The categories described in the above figure are for illustration only. Different diameters and materials may be more appropriate in different countries.

Start by entering into the table the number of kilometres of pipe of each category in the entire distribution system. Next, decide how many sections of pipeline from each category should be chosen for the experiments. The aim is to identify a sample of experimental pipeline sections which are representative of the network as a whole. The number of test sections in each category should generally be proportional to the number of kilometres in the network and to the expected variability of leakage rates. The leakage rates from PE pipes are expected to be less variable than those from cast iron pipes and so fewer tests are required for a given size of population for PE pipes than for cast iron to establish the leak rate to the same level of uncertainty.

For each section of ‘main’ identified agreement will be needed from the customer supplied by that main to allow interruption of their supply for the duration of the test. Each section of pipe to be isolated should be approximately 1km long. The service pipe should be capped on the customer’s side of the meter isolation valve.

Two pressure decay experiments are required for each isolated section of pipe. In one test a leak of known magnitude is introduced into the pipeline under test and a pressure decay curve plotted. In the other the control leak is stopped. From the two pressure decay curves it is possible to calculate the rate of gas leakage from the test section without prior knowledge of the internal volume of the section.

Leak rates should be determined in this way for a number of different pressures, both above, below and at the normal operating pressure of the main.

The leak rate should also be determined with the service pipe disconnected from the main. This allows separate leak rates to be calculated for the service pipe. Service pipes are made of a number of different materials and the sample of test mains should include service pipes of all the materials used.

Default emission factor: 88 m^3/km/year/mbar including leakage from service pipes. The emission factors f_{Lj}, and f_{Lu} can be calculated from these figures using the pressure in the pipe and the composition of the gas (to estimate the weight of $1m^3$ of gas), (from reference 2)

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SOURCE ACTIVITY TITLE : Geothermal Energy Extraction

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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