



National Pollutant Inventory

Emission Estimation Technique Manual

for

**Oil & Gas
Exploration & Production**

**EMISSION ESTIMATION TECHNIQUES
FOR
OIL & GAS EXPLORATION & PRODUCTION**

TABLE OF CONTENTS

1.0 Introduction	1
2.0 Process Description	2
3.0 Potential Emissions	3
3.1 Elements of the Environment.....	3
3.1.1 Emissions to Air	3
3.1.2 Emissions to Water	3
3.1.3 Emissions to Land.....	4
3.1.4 Transfers.....	4
4.0 Emission Estimation Techniques.....	5
4.1 Threshold Calculation- Trigger Test.....	8
4.2 NPI Substances.....	8
4.2.1 Category 1 and 1a Substances	8
4.2.2 Category 2A and 2B Substances.....	14
4.2.3 Category 3 Substances.....	15
5.0 Assumptions	29
5.1 Produced Formation Water (PFW)	29
5.2 Storage Tank Emissions	29
5.3 Sources of Information	29
5.4 Emission Factors.....	29
5.5 Facility Specific Factors	29
5.6 Flaring	30
5.7 Conversion of Units	31
6.0 Definitions	32
7.0 References	33
7.1 References Cited in Text.....	33
7.2 References Not Cited in Text.....	34

OIL & GAS EXPLORATION & PRODUCTION

LIST OF FIGURES AND TABLES

Figure 1:	Potential Sources of NPI Substance Emissions	2
Table 1:	Indicative Population Figures for Wastewater NPI Threshold Tripping.....	16
Table 2:	Calculation Worksheet for Determining Category 1 and 1a Substance Usage from Produced Formation Water (PFW)	17
Table 3:	Calculation Worksheet for Determining Category 1 and 1a Substance Usage from Crude Oil / Gas Throughput.....	17
Table 4:	Calculation Worksheet for Drilling Fluids.....	18
Table 5:	Calculation Worksheet for Fugitive Emissions.....	18
Table 6:	Average Emission Factors for Oil and Gas Process Fugitives.....	19
Table 7:	Definition of Service Types for Equipment	20
Table 8:	Speciation Fractions for Fugitive TOC Emissions.....	20
Table 9:	Calculation Worksheet for Fugitive Emissions	21
Table 10:	Calculation Worksheet for Flaring	22
Table 11:	Calculation Worksheet for Loading Losses	22
Table 12:	Calculation Worksheet for Venting	22
Table 13:	Calculation Worksheet for Venting of TOCs from FPSO Crude Oil Storage Tanks	23
Table 14:	Calculation Worksheet for Wastewater Discharges.....	23
Table 15:	Calculation Worksheet for Emissions of CO, NO_x and VOC from Combustion of Gas (Associated and Non-Associated)	24
Table 16:	Calculation Worksheet for Emissions of CO, NO_x and VOC from Power Generation – Diesel Equipment.....	24
Table 17:	Calculation Worksheet for Emissions of PM₁₀ and Organics from Associated Gas Combustion	25
Table 18:	Calculation Worksheet for Emissions of PM₁₀ and Organics from Non-Associated Gas Combustion	25
Table 19:	Calculation Worksheet for Emissions of PM₁₀ and Organics from Diesel Combustion (less than 600 hp)	26
Table 20:	Calculation Worksheet for Emissions of PM₁₀ and Organics from Diesel Combustion (greater than 600 hp)	26
Table 21:	Calculation Worksheet for Emissions of Metals from Diesel Combustion..	27
Table 22:	Calculation Worksheet for Emissions of Metals from Associated Gas Combustion.....	27
Table 23:	Calculation Worksheet for Emissions of Metals from Non-Associated Gas Combustion.....	28
Table 24:	Calculation Worksheet for Total N and Total P in Wastewater Flows	28

1.0 Introduction

The purpose of all Emission Estimation Technique (EET) manuals in this series is to assist Australian manufacturing, industrial, and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in oil and gas exploration and production, both on and off shore.

The separation and conditioning of hydrocarbons is included in this manual, up to the point of loading and transport of hydrocarbons to the refinery only.

Emissions from crude oil transport are included for loading of product only, and not for emissions while in transit.

Emissions from the refining of crude oil and petrochemical processing are not covered by this manual.

EET MANUAL : Oil & Gas Exploration & Production

HANDBOOK : Oil and Gas Extraction

ANZSIC CODE : 120

This manual has been prepared by PPK Environment & Infrastructure in conjunction with the NSW Environment Protection Authority on behalf of the Commonwealth Government.

The manual has been developed through a process of national consultation involving key industry stakeholders and State and Territory environmental authorities. Particular thanks are due to the Australian Petroleum Production and Exploration Association (APPEA), and its members for their comments, advice and information.

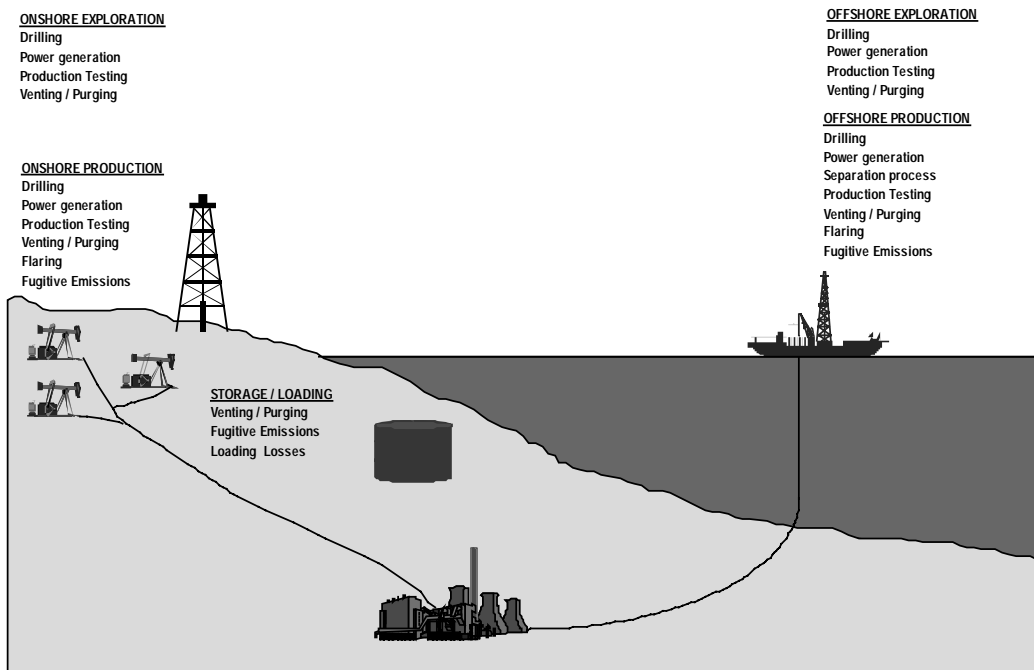
2.0 Process Description

Petroleum exploration and production operations are conducted both onshore and offshore and encompass the following activities:

1. **Exploration**
 - Seismic (Note that emissions from this activity are NOT reportable under the NPI)
 - Exploration and appraisal drilling
 - Production testing
2. **Production**
 - Development drilling
 - Separation and processing
 - Storage
 - Loading
 - Associated service activities such as work boat and helicopter operations that link and support facilities and their bases. (Note that such activities are classed as mobile sources, and emissions from such activities are NOT reportable under the NPI)

Figure 1 illustrates the potential sources of emissions of NPI substances from Oil & Gas Production and Exploration.

Figure 1: Potential Sources of NPI Substance Emissions



(Adapted from APPEA, 1997)

3.0 Potential Emissions

The NPI Guide at the front of this Handbook details all of the reportable substances under the NPI, and their associated thresholds. This information should be consulted to determine whether or not your facility handles, manufactures, or otherwise uses any of the substances in excess of the defined thresholds (and, therefore, whether emissions of the substances are to be reported).

3.1 Elements of the Environment

3.1.1 Emissions to Air

Air emissions may be categorised as:

- Point source emissions (eg fuel combustion, flares) where the release is through single point sources into the atmosphere; and
- Fugitive emissions (eg volatilisation of vapour from open vessels, and equipment leaks such as valves and flanges).

3.1.2 Emissions to Water

Emissions of substances to water can be categorised as discharges to:

- Surface waters (eg. lakes, rivers, dams, and estuaries);
- Coastal or marine waters; and
- Stormwater.

For the purposes of reporting to the NPI, emissions to groundwater are considered as emissions to land, and not to water.

Generally, the most accurate method for determining emissions to the environment via wastewater is to use direct measurement, where such information is available. If unavailable, default emission factors have been provided to assist you in meeting your reporting requirements under the NPI.

Spills to water are included within the NPI process. The mass of NPI substances in unrecovered material must be included in reports as an emission to the environment.

3.1.3 Emissions to Land

Emissions of substances to land, on- or off-site include:

- uncontained solid wastes,
- slurries,
- sediments; and
- spills and leaks.

The discharge of listed substances to a sewer does not require you to report to the NPI (See Section Three of *The NPI Guide*).

Spills to land are included within the NPI process. The mass of NPI substances in unrecovered material must be included in reports as an emission to the environment.

3.1.4 Transfers

Within the oil and gas exploration and production industry, transfers will include:

- reinjection of Produced Formation Water (PFW) and gas;
- wastes managed by an off-site facility;
- discharges to sewer; and
- discharges to surface impoundments, such as balancing ponds and treatment plants.

While the reinjection of PFW is classed as a transfer, any NPI substances contained in production chemicals that are added to the PFW (such as scale inhibitor) must be reported (Decision of NPI Implementation Working Group, Meeting of 20-21 April 1998).

Transfers are not required to be reported under the NPI.

4.0 Emission Estimation Techniques

Estimates of emissions of NPI listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in *The NPI Guide* at the front of this Handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility. The four types described in the *NPI Guide* are:-

- sampling or direct measurement
- mass balance
- fuel analysis, or other engineering calculations
- emission factors

Select the EET (or mix of EETs) that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of emission estimation techniques that are not outlined in this Handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this Manual does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site specific emission factors, you may use these if approved by your relevant environmental authority.

In general, direct measurement is the most accurate method for characterising emissions and, where available, such data should be used in preference to other EETs presented in this Manual. However, additional direct measurement is not required under the NPI Measure. Direct monitoring may be undertaken as an element of other EETs.

You should note that the EETs presented in this Manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (eg: spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, ie. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

For the purposes of this Handbook, the EETs that can be used for estimating annual emissions, for reporting under the NPI include:

▪ **Emission Factors**

Emission factors are commonly used in the estimation of emissions to air because of the cost and technical difficulties associated with the direct monitoring of emissions. In principle, all emission factors are applied in the same way. The emission factor is simply multiplied, as appropriate, by a mass or volume flow type figure (eg. total gas burnt, or total oil produced) to enable total loadings of each substance to be calculated. Although there may be overlaps between emission factors for the same processes in different industries, the use of specific fuels requires that they be listed separately in each manual.

Emission factors for calculation of emissions of NPI substances from combustion, fugitive emissions, flaring and loading are presented in the Worksheets in Tables 2 to 24 of this Manual.

▪ **Mass Balance**

Mass balance provides an estimate of emissions when materials containing known concentrations of substances are used in a process or facility. This approach is most appropriate where inputs and outputs from a process are quantifiable. Examples include:

- Workover/cementing;
- Drilling mud;
- Production chemicals;
- Pipeline additives;
- Cathodic protection; and
- Antifouling agents.

Using mass balance, the emissions may be calculated using the standard equation below. The material lost to the environment then needs to be assigned to air, water and/or land.

$$\text{Mass lost to the environment} = \text{Mass added} - \left[\text{Mass of known transfers} + \text{Mass recovered} \right]$$

▪ **Modelling**

Modelling may be the most appropriate means of estimating emissions from particular sources (eg. dehydrators) and may be used to assist in the compilation of emissions data. Models and software packages of relevance to the oil and gas industry include:

- GRI-GLYCalc - Gas Research Institute [<http://www.gri.org>]
- E&P Tank - API / GRI [<http://www.api.org/ehs/old%20rh/E&PTANK&EPEC.htm>]
- Exploration and Production Emissions Calculator (EPEC) – API [<http://sonomatech.com.epec/>]

- **Direct Measurement or Source Monitoring**

As previously mentioned, direct measurement is generally the most accurate method for characterising emissions and, where such data is The NPI does not require you to undertake direct measurement in addition to that which you already perform under the Measure. Direct monitoring can also be undertaken as an element of other EETs. For example, the volume of gas flared may be measured by a flare flowmeter. This information combined with information on gas composition will enable an estimate to be made of combustion gases from flaring to be made.

It must be noted that total facility emissions are estimated by calculating emissions from individual sources, and then adding each of these to provide a cumulative estimate.

The following sections provide guidance to help you determine:

- whether you need to report;
- what substances you need to report; and
- where reporting is required, and how to calculate emissions of those substances (including the identification of the sources, or potential sources of emissions, and the provision of suitable EETs for estimating emissions).

4.1 Threshold Calculation– Trigger Test

The following table identifies the basic production and material consumption information that is required to apply the EETs presented in this manual.

Throughput per year (unless maximum rate)			
Production	- Liquids	=	tonnes
		=	Litres
	- Gas (Total)	=	tonnes
	Associated	=	tonnes
	Non-Associated	=	tonnes
Fuel Consumed	- Liquids	=	tonnes
	- Gas (Total)	=	tonnes
	Associated	=	tonnes
	Non-Associated	=	tonnes
Flaring	- Gas		tonnes
	- Liquids / Oil		tonnes
Drilling Fluids		=	Litres
Production Chemicals		=	tonnes
Hydrocarbon Storage		=	tonnes
Produced Formation Water		=	Litres
Other Wastewater		=	Litres
Energy consumption of the Facility		=	MW Hrs*
Maximum potential power consumption		=	MW _x
<u>Maximum</u> rate of combustion		=	tonnes / hour

* MW Hrs = megawatt hours x MW = megawatts

4.2 NPI Substances

4.2.1 Category 1 and 1a Substances

The reporting criteria for Category 1 and 1a substances, as detailed in Clause 10 of the NPI NEPM, are:

- a Category 1 listed substance is only reportable if 10 tonnes or more of the substance is used per annum;
- the only Category 1a substance is Total Volatile Organic Compounds (VOCs) for which

the throughput threshold is 25 tonnes per annum;

- “use” means processed (eg. crude oil throughput, production chemicals, drilling fluids), or coincidental production (eg substances contained in produced formation water, emissions from dehydrator regeneration etc); and
- substances in proprietary mixtures are not reportable unless the substance is specified in a Material Safety Data Sheet or, in the case of any other material, the occupier of the facility could reasonably be expected to know that the substance is contained in the material.

The usage of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for VOCs) reporting threshold is exceeded. If the threshold is exceeded, emissions of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

The total amount of each Category 1 and 1a substance ‘used’ must be calculated in order to determine whether the threshold is exceeded. This involves developing a cumulative total for the use of each NPI substance from various sources.

Produced Formation Water (PFW)

PFW will vary between facilities and reservoirs (refer to Section 5.1 of this Manual). However, a generic PFW composition has been developed for the purposes of reporting to the NPI. This generic composition has been developed by APPEA, in consultation with industry, by averaging PFW analyses across numerous sites from a number of companies.

The generic composition can be used by facilities in the absence of facility specific data. Where facility specific data is available, this should be used in preference to the default values provided in Table 2 of this Manual.

Emissions of NPI substances from PFW can be estimated using the calculation worksheet provided in Table 2. In determining usage of Category 1 and 1a substances, the emissions calculated from Table 2 will correspond to the ‘use’ of those substances associated with PFW. The emissions will need to be added to the use of NPI substances from other activities / sources to determine whether the 10 tonne per annum threshold is exceeded for a particular facility.

You should note that the reinjection of PFW is classed as a transfer. While transfers are not required to be reported under the requirements of the NPI, any NPI substances contained in production chemicals that are added to the PFW (such as scale inhibitor) must be reported.

Throughput – Crude Oil / Gas

Crude oil consumption will vary between facilities and reservoirs. Facilities should use existing crude oil composition data to determine NPI substance ‘usage’.

The calculation worksheet provided in Table 3 can be used to determine the contribution

of crude oil to the total usage of Category 1 and 1a substances at a facility. These will need to be added to other Category 1 and 1a substance usage (eg. from PFW) to determine total usage for a facility.

Drilling Fluids

Drilling fluids may be discharged to the environment through either direct losses, or adhered to drill cuttings.

The concentration of NPI substances in drilling fluids will vary according to the type and manufacturer of drilling fluid used. It is recognised that information on the composition of drilling fluids is not readily available. Therefore, information on the concentration of NPI substances in drilling fluids will need to be derived from suppliers and manufacturers.

Losses of drilling fluids, and the component NPI substances, may be estimated using a mass balance approach, and taking into account:

- total volume of drilling fluid used;
- down hole losses (such losses are required to be reported as releases to land);
- volume of drilling fluid recovered

The balance of these losses, as expressed in the equation below, may be considered to be losses to the environment:

$$\begin{array}{l} \text{Volume lost to the} \\ \text{environment} \\ \text{(Litres)} \end{array} = \begin{array}{l} \text{Total} \\ \text{volume of} \\ \text{fluid used} \\ \text{(Litres)} \end{array} - \left[\begin{array}{l} \text{Down hole} \\ \text{losses of} \\ \text{fluid} \\ \text{(Litres)} \end{array} + \begin{array}{l} \text{Volume of} \\ \text{fluid} \\ \text{recovered} \\ \text{(Litres)} \end{array} \right]$$

In order to estimate the emission of NPI substances to the environment the 'Volume lost to the environment' for each relevant NPI substance must be multiplied by the concentration of that NPI substance in the drilling fluid.

$$\begin{array}{l} \text{Emission of NPI} \\ \text{substance to the} \\ \text{environment} \\ \text{(kg)} \end{array} = \left[\begin{array}{l} \text{Volume lost to} \\ \text{the environment} \\ \text{(Litres)} \end{array} \times \begin{array}{l} \text{Concentration of} \\ \text{NPI substance in} \\ \text{drilling fluid} \\ \text{(mg / Litre)} \end{array} \right] \times 1000$$

A worksheet to assist you with estimating the emissions of NPI substances associated with drilling fluids is provided in Table 4.

The quantity of NPI substances used in drilling fluids will also need to be added to other Category 1 and 1a substance usage (for example, from PFW and crude oil/gas) to determine total usage for a facility.

Fugitive Emissions

Process fugitive sources within the oil and gas exploration and production sectors include:

-
- valves;
 - flanges;
 - pumps;
 - connectors;
 - compressors; and
 - drains (onshore).

For the purposes of reporting to the NPI, the use of average emission factors is recommended. Two methods of calculation are available to estimate fugitive emissions. These methods are detailed below (NB. it is likely that Method 1 will be most suitable for the majority of facilities).

Method 1

In 1995, APPEA developed a suite of generic emission factors for characterising fugitive emissions from the oil and gas exploration and production industry in Australia.

Process fugitive emissions can be estimated using the calculation worksheet in Table 5. Fugitive emissions from storage tanks can also be estimated using the emission factors in Table 5.

Once the fugitive emissions have been calculated, the speciation fractions in Table 8 can be applied using the calculation worksheet in Table 8. Only columns 'E_{TOC}', 'SF' and 'E_{SF}' in Table 9 are used when Method 1 is applied.

Method 2

For process fugitive emissions, average emission factors have been derived from the USEPA, 1995 and API, 1996, and are provided in Table 6. Total fugitive emissions may be calculated using the calculation worksheet provided in Table 9.

The following data is required for 'average emission factors' estimation calculations:

- The number of each type of component (eg. valves, flanges, etc.) in each process unit;
- The service each component is in (eg. gas, light liquid, heavy liquid, water/oil). The definitions in Table 7 should be used when determining the type of 'service' a particular piece of equipment is in, so that the appropriate emission factors are used.
- The weight fraction of Total Organic Compounds (TOC) within the steam; and
- Hours operational (eg hours/year). Hours of operation should be determined for particular streams as detailed above.

The emission factors are presented on a 'per individual source' basis. However, the factors are most valid for estimating emissions from a population of equipment, and are not intended for use when estimating emissions from an individual piece of equipment over a short time period (eg. several hours).

An example calculation is presented in Appendix A. (You should note that steps used in the average emission factors approach to fugitive emissions estimation have been based on the steps detailed in the *Emission Estimation Technique Manual for Petroleum Refining*, and amended to suit the oil and gas exploration and production industry).

You should also note that the emission factors presented in Table 6 only apply to process fugitive emissions. Emissions from storage tanks will need to be calculated separately using the emission factors in Table 5. These emissions will also need to be speciated using the speciation fractions presented in Table 8. The calculation worksheet in Table 9 may be used to speciate emissions from storage tanks (only columns 'E_{TOC}', 'SF' and 'E_{SF}' in Table 9 are required to be used for these calculations).

Flaring

Emissions of NPI substances from flaring can be calculated using the calculation worksheet provided in Table 9.

Tables 16, 17, 21 and 22 can be applied to gas flaring data, in the absence of facility specific information data to estimate emissions of metals and organics.

Tables 19 and 20 can be applied to liquids flaring data (in absence of facility specific information) to estimate emissions of metals and organics.

Loading Operations

Emissions from the loading of crude product to tankers can be estimated using the calculation worksheet in Table 11.

In the absence of other information, the speciation factors presented in Table 8 can be used to provide estimates on the composition of the emitted VOCs.

Venting

The volume of waste gas vented can be calculated using a mass balance approach as detailed below:

$$G_V = G_P - (G_S + G_F + G_{Fl})$$

Where :	G_V	=	Mass of gas vented
	G_P	=	Mass of gas produced
	G_S	=	Mass of gas sold / processed
	G_F	=	Mass of gas lost as fugitive emissions
	G_{Fl}	=	Mass of gas flared

The estimation of gas vented (G_V) is detailed in Table 12.

In the absence of other information, the speciation factors for gas presented in Table 8 can be used to provide estimates on the composition of the emitted VOCs.

Venting from crude oil storage tanks

Venting from the crude oil storage tanks on an FPSO (floating production storage and offloading facility) may be estimated using the factor presented below. (This factor is derived from USEPA, (1995b), and relates to TOC losses from tankers in transit to refineries.)

$$\text{TOC emissions (kg/day m}^3 \text{ of stored crude)} = 0.0223$$

The estimation of TOC emissions from crude oil storage tanks is detailed in Table 13. In the absence of other information, the speciation factors presented in Table 8 can be used to provide information on the composition of the emitted TOCs.

Wastewater

Wastewater streams are likely to be treated at a common point at onshore facilities, while offshore facilities are likely to discharge treated and untreated wastewater from a number of points. If available, existing monitoring data should be used.

Direct measurement data can be supplemented by a range of data including:

- Manufacturers' specifications for treatment packages; and
- Material/chemical mass balance.

When considering wastewater discharges, you should consider the definition of 'transfer'. Reporting is only required for those releases that are not classed as transfers (see Section 3.1.4).

The estimation of NPI substance emissions from wastewater discharges is detailed in Table 14.

General guidance on the characterisation of process wastewater streams is provided in *Emission Estimation Technique Manual for Sewage and Wastewater Treatment*.

Spills and Leaks

A mass balance EET can also be applied to emissions of NPI substances as a result of accidental spills and leaks.

The mass balance would require consideration of:

- the total volume of material spilled or leaked; and
- the volume of material recovered.

The difference between these volumes would be considered to be losses to the environment.

As with drilling fluids, the proportion of NPI substances within the material must be determined. Emissions of NPI substances to the environment could then be estimated by multiplying the volume of material lost to the environment, by the proportion of NPI

substances present in the spilled material.

Information on the composition of spilled materials may be obtained from either suppliers or manufacturers (eg production chemicals), or through direct measurement (eg crude oil).

4.2.2 Category 2A and 2B Substances

Reporting for some substances is triggered by the usage of fuel. To determine whether Category 2a or 2b thresholds are exceeded, the total fuel burnt must be calculated. This will require comparing annual and peak hourly fuel usage with the Category 2a and 2b thresholds. *The NPI Guide* should be referred to for more details.

Combustion - General

Emissions of NPI substances from combustion activities can be calculated using the calculation worksheets provided in Tables 15 to 23.

For gas, the specific emission factors presented for the combustion of associated gas (Tables 17 and 22) and non-associated gas (Tables 18 and 23) should be used. Otherwise, you should use the general emission factors presented in Table 15.

Similarly, when estimating emissions from diesel combustion, the specific emission factors provided for turbines, engines, or heaters should be used (Tables 16 and 21). Where specific emission factors are not provided, use the general emission factors for combustion for equipment of greater than, and less than 600 hp as appropriate (see Tables 19 and 20).

Sulfur Dioxide Emissions from Combustion

Fuel analysis can be used to predict emissions of SO₂ resulting from combustion activities (eg power generation, flaring etc.).

The basic equation used in fuel analysis emission calculations is the following:

$$E_i = Q_f * \text{substance concentration in fuel} * (MW_p / EW_f)$$

where:

E_i	=	emissions of substance (kg/hr)
Q_f	=	rate of fuel use (kg/hr)
MW_p	=	molecular weight of substance emitted (kg/kg-mole)
EW_f	=	elemental weight of substance in fuel (kg/kg-mole)

For instance, SO₂ emissions from oil combustion can be calculated based on the concentration of sulfur in the oil or gas. This approach assumes complete (100%) conversion of sulfur to SO₂. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO₂ (MW = 64) are emitted.

$$\text{Emission of SO}_2 \text{ (kg/hr)} = \text{Fuel Usage (kg/hr)} * \frac{\text{wt \% S}}{100} * \frac{MW_{SO_2}}{EW_s}$$

Where: wt % S = weight percent of sulfur (as elemental S) in the fuel.
 $MW_{SO_2} = 64$
 $EW_s = 32$

The emissions are estimated as kg/hr and as such, should be multiplied by the number of hours of operation in a year in order to determine the annual emissions.

Hydrogen sulfide (H₂S) is generally routed to flare following its stripping from the gas stream. H₂S is converted to SO₂ in the flaring process, and emissions may be calculated based on the efficiency of flaring conversion of H₂S to SO₂ (assume 100%), and the H₂S content of the gas. A similar calculation to that for fuel combustion can be applied to the combustion of H₂S to estimate SO₂ emissions, as shown below:

$$\text{Emission of SO}_2 \text{ (kg/hr)} = \text{Volume of gas to be flared (kg/hr)} * \frac{\text{wt \% H}_2\text{S}}{100} * \frac{MW_{SO_2}}{MW_{H_2S}}$$

Where: wt % H₂S = weight percent of H₂S in the gas to be flared.
 $MW_{SO_2} = 64$
 $MW_{H_2S} = 34$

The 'volume of gas to be flared' may refer to either the waste H₂S gas stream, or the total volume of all gas to be flared. Whichever volumetric flow is used, it is essential that the 'wt % H₂S' relates to that gas stream in order to ensure that emission estimations are valid.

Metals Emissions from Combustion

Where fuel analysis data is available for metals, this data can be used to estimate emissions of various NPI-listed metals in preference to the default emission factors provided in Tables 21, 22 and 23.

These emissions are calculated by assuming that all metals in the fuel are emitted to air (ie. therefore, no metals are contained in fuel ash). While this is somewhat conservative in most cases, this approach will provide a much more accurate characterisation of metals emissions than use of the default emission factors.

4.2.3 Category 3 Substances

Category 3 substances are nitrogen and phosphorus. These are reportable if emissions to water (excluding groundwater) from sewerage exceed the following scheduled amounts:

- 15 tonnes per year of total nitrogen; and,
- 3 tonnes per year of total phosphorus

While the emission of nitrogen and phosphorus to water from facilities is unlikely to exceed the reporting threshold, it is the responsibility of each facility to determine whether this is the case. The table below suggests the indicative facility population likely to result in exceedence of the Category 3 thresholds.

Based on the West Australian Water Corporation wastewater treatment design criteria, the

per person per day loading of total nitrogen and phosphorus has been calculated. This data has been applied to the NPI reporting thresholds to provide an indicative facility population that will exceed the reporting thresholds.

Table 1. Indicative Pollution Figures for Wastewater NPI Threshold Tripping

	kg per person per day	Indicative facility population
Total Nitrogen	0.011	3736
Total Phosphorus	0.0025	3288

Derived from West Australian Water Corporation wastewater treatment design criteria.

Assumes: Annual dry weather flow of 200 litres per person per day
Total nitrogen concentration of 55 mg/L (range of 40 – 70 mg/L)
Total phosphorus concentration of 12.5 mg/L (range of 10 – 15 mg/L)
365 days per year of N and P loading

The estimation of total N and total P from wastewater discharges is detailed in Table 24.

Table 2: Calculation Worksheet for Determining Category 1 and 1a Substance Usage from Produced Formation Water (PFW)

	Zn	As	Ni	Cd	Cr	Pb	Mn	Cu	Hg	Benzene	Toluene	Ethyl benzene	Xylenes	Phenol	VOCs
Substance Concentration [SC]* (mg/L)	0.0063	0.0010	0.0099	0.0063	0.0070	0.0066	1.7146	0.0074	0.0010	1.0099	1.5199	0.0710	0.8600	3.6098	
Throughput of PFW [⊗] [T] (L / year)															
Emission = [SC] * [T] / 10 ⁶ (kg / year)															

* Source: APPEA, 1998. [⊗]ie the quantity of PFW released / discharged

Table 3: Calculation Worksheet for Determining Category 1 and 1a substance usage from Crude Oil / Gas Throughput

	Zn	As	Ni	Cd	Cr	Pb	Mn	Cu	Hg	Benzene	Toluene	Ethyl benzene	Xylenes	Phenol	VOCs
Substance Concentration [SC]* (mg/L)															
Throughput of crude oil [T] (L / year)															
Emission = [SC] * [T] / 10 ⁶ (kg / year)															

Source: PPK, 1998

* Facilities will need to provide their own crude oil composition for each of the substances listed. It should be recognised that NPI substances other than those listed above, may also be relevant to a facility. In determining whether or not reporting is required, it may be necessary to consider these substances (eg. hydrogen sulfide).

Table 4: Calculation Worksheet for Drilling Fluids

Volume of fluid used [V _U] (L/year)	Volume of fluid recovered [V _R] (L/year)	Volume of fluid lost down hole [V _{DH}] (L/year)	Volume of fluid emitted to the environment [V _E] V _U - (V _R + V _{DH}) (L/year)	Concentration of NPI substance in fluid [C] (mg/L)	Mass of NPI substance emitted to the environment* [E] (V _E + V _{DH}) * C / 1,000,000 (kg/year)

* Source: PPK, 1998.

+ Note that the volume of fluid lost down hole should be reported as a repeat to land. The allocation of the volume of fluid emitted to the environment to air, water and/land will depend on the mechanisms by which the drilling fluid is lost to the environment.

Table 5: Calculation Worksheet for Fugitive Emissions +

	General Leaks	Fixed Roof Tank	Floating Roof Tank	Internal Floating Roof Tank
	VOC	VOC	VOC	VOC
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.000007	0.000112	0.00000085	0.00000007
Throughput of all product (oil and gas) [T] (tonnes / year)				
Emission = [EF] * [T] * 1000 (kg/year)				

* Source: APPEA, 1997.

+ For more information on fugitive emissions from tanks, please refer to the *EET Manual for Fuel and Organic Liquid Storage*.

Table 6: Average Emission Factors* for Oil and Gas Process Fugitives. ^(a)

Equipment Type	Service ^(f)	Emission Factor (kg/hr/source)
Valves	Gas	4.5×10^{-3}
	Heavy Oil	8.4×10^{-6}
	Light Oil	2.5×10^{-3}
	Water/Oil	9.8×10^{-5}
Pump Seals	Gas	2.4×10^{-3}
	Heavy Oil	NA
	Light Oil ^(e)	0.013
	Water/Oil	2.4×10^{-5}
Others ^(d)	Gas	8.8×10^{-3}
	Heavy Oil	3.2×10^{-5}
	Light Oil	7.5×10^{-3}
	Water/Oil	0.014
Connectors ^(b)	Gas	2.0×10^{-4}
	Heavy Oil	7.5×10^{-6}
	Light Oil	2.1×10^{-4}
	Water/Oil	1.1×10^{-4}
Flanges	Gas	3.9×10^{-4}
	Heavy Oil	3.9×10^{-7}
	Light Oil	1.1×10^{-4}
	Water/Oil	2.9×10^{-6}
Open-ended Lines	Gas	2.0×10^{-3}
	Heavy Oil	1.4×10^{-4}
	Light Oil	1.4×10^{-3}
	Water/Oil	2.5×10^{-4}
Drains (onshore) ^(c)	All	0.032

* USEPA, 1995a & API, 1996 [both quote the same emission factors unless otherwise indicated]

a These factors are for total volatile organic compound emission rates (including non-VOC's, such as methane and ethane), and apply to light crude, heavy crude, gas plant, and off-shore facilities. "NA" indicates that not enough data was available to develop the indicated emission factor.

b Defined as non-flanged connectors.

c Source: Emission Estimation Technique Manual for Petroleum Refining, Table 13.

d This 'other' category should be applied to all equipment types in heavy liquid service that have not been specifically considered elsewhere in the table. Note, however, that some equipment types have emission factors applicable to 'All' service types, including the heavy liquid category. Therefore, care must be taken to ensure that these are NOT included under the 'other' category.

e Applicable to agitator seals where no other data is available.

f Water/Oil emission factors apply to water streams in oil service with a water content greater than 50%, from the point of origin, to the point where the water content reaches 99%. For water streams with a water content greater than 99%, the emission rate is considered negligible.

Heavy Oil : < 20 API Gravity

Light Oil : > 20 API Gravity

Table 7: Definition of Service Types for Equipment

Service Type	Definition
Gas/vapour	Material is in a gaseous state at operating conditions
Light liquid	Material is in a liquid state in which the sum of the concentrations of individual constituents with a vapour pressure over 0.3 kilopascals (kPa) at 20°C, is greater than, or equal to, 20 weight percent (wt %);
Heavy liquid	Material does not fall under the classifications for gas/vapour, or light liquid service
Water/Oil	Water streams in oil service with a water content greater than 50%, from the point of origin to the point where the water content reaches 99%. For water streams with a water content greater than 99%, the emission rate is considered negligible.

Source: API, 1996

Table 8: Speciation Fractions* For Fugitive TOC Emissions

Substance	Gas	Heavy Oil	Light Oil	Water/Oil
VOC	0.171	0.030	0.296	0.296
n-hexane ^(a)	0.00693	0.00752	0.02300	0.02300
Benzene	0.00069	0.00935	0.00121	0.00121
Toluene	0.00038	0.00344	0.00105	0.00105
Ethylbenzene	0.00003	0.00051	0.00016	0.00016
Xylenes	0.00009	0.00372	0.00033	0.00033

*Source: API, 1996

^a upper limit of n-hexane based on C6+ fraction.

Table 9: Calculation Worksheet for Fugitive Emissions ^{*1}

Source of Fugitive Emission^(a)	(N) No. Pieces of Equipment	(W_{TOC}) Average Weight Fraction	(F_A) Average Emission Factor - Table 5 -	(E_{TOC}) Emission Rate of TOC = (F_A * W_{TOC} * N)	(HRS) Hours of Operation	(SF) Speciation Fraction - Table 7 -	[E_{SF}] Speciated Substance Emission = (E_{TOC} * HRS * SF) (kg/year)

¹ Source: based on API 1996.

* The speciation to relevant NPI substances from calculated TOC emissions must be carried out for each species identified in Table 7.

(a) See Table 5 for list of equipment types, and Table 6 for definitions of the service for these items.

E_{TOC} Emission rate of TOC from all sources grouped in a particular equipment type and service (kg/hr). (eg. valves in light liquid service). For further guidance on this, see Table 6.

F_A Applicable average emission factor for the equipment type (Table 5)

W_{TOC} Average weight fraction of TOC in the stream (eg 80% TOC and 20% water vapour gives value of 0.8). Where a TOC fraction is assumed, this information must be recorded.

N The number of pieces of equipment grouped in the relevant category according to:

- equipment type,
- service; and
- weight fraction of TOC.

E_{TOC} Emission rate of TOC from all sources grouped in a particular equipment type and service (kg/hr)

Hrs Hours of operation in the reporting year for each type of equipment and stream

SF Speciation fraction (from Table 8)

E_{SF} Speciated Substance Emission (kg/yr)

Table 10: Calculation Worksheet for Flaring

	Gas Flared (Associated & Non-associated)			Liquids / Oil Flared		
	CO	NO _x	VOC	CO	NO _x	VOC
Emission Factor* [EF] (tonnes emissions/ tonnes throughput)	0.0087	0.001581	0.015	0.018	0.0037	0.00297
Throughput [T] (tonnes / year)						
Emission = [EF] * [T] * 1000 (kg / year)						

* Source: E&P Forum 1994.

Table 11: Calculation Worksheet for Loading Losses

	Rail/Truck Loading Losses	Ship Loading Losses
	VOC	VOC
Emission Factor* [EF] (tonnes emissions/ tonnes throughput)	0.00033	0.0001
Throughput [T] (tonnes / year)		
Emission = [EF] * [T] * 1000 (kg / year)		

* Source: E&P Forum 1994.

Table 12. Calculation Worksheet for Venting*

Mass of Gas Produced [G _p] (kg/year)	Mass of Gas sold / processed [G _s] (kg/year)	Mass of Gas lost as fugitives [G _f] (kg/year)	Mass of Gas Flared [G _n] (kg/year)	Mass of Gas Vented [G _v] G _p - (G _s + G _f + G _n) (kg/year)

Source: PPK, 1998

* Volumes of gases may be converted to masses using the standard densities below (E&P Forum, 1994):

- associated gas : 1 tonne / 1000 m³
- non-associated gas : 0.8 tonne / 1000 m³

See Section 5.7 for a further discussion of this conversion.

Table 13: Calculation Worksheet for Venting of TOCs from FPSO Crude Oil Storage Tanks

Crude Oil Storage Tank No. ^(*)	No. of days stored [N] (days)	Volume of Crude stored [V] (m ³ / day)	TOC Emission Factor [E _r] (kg/day m ³)	Mass of TOCs emitted [E _{TOC}] E _r * V * N (kg/year)
			0.0223	
			0.0223	
			0.0223	
			0.0223	

Source: USEPA, 1995b

* TOC emissions may be estimated from individual tanks, or from facility as a whole.

Table 14: Calculation Worksheet for Wastewater Discharges

Wastewater Discharge ^(*)	Volume of wastewater discharged [V] (L / year)	Concentration of NPI substance ⁽⁺⁾ [C] (mg/L)	Mass of NPI substance emitted [E] V * C / 1,000,000 (kg/year)

Source: PPK, 1998

* Emissions from wastewater can be calculated at individual discharge points, or for the facility as a whole.

+ Concentrations are assumed to be from 'end of pipe' following any treatment process. Where concentrations are taken prior to the treatment process, the efficiency of the treatment process must be factored into the EET.

Table 15: Calculation Worksheet for Emissions of CO, NO_x and VOC from Combustion of Gas (Associated and Non-Associated⁽⁺⁾)

	Turbines			Engines			Heaters		
	CO	NO _x	VOC	CO	NO _x	VOC	CO	NO _x	VOC
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.0027	0.00692	0.000051	0.0096	0.07622	0.003	0.0008	0.00332	0.00062
Throughput [T] (tonnes of assoc gas / year)									
Emission = [EF] * [T] * 1000 (kg / year)									

* Source: E&P Forum, 1994.

+ Associated gas is the gas produced from an oil and gas extraction operation, while non-associated gas is the gas from a well that only produces gas.

Table 16: Calculation Worksheet for Emissions of CO, NO_x and VOC from Power Generation – Diesel Equipment

	Turbines			Engines			Heaters		
	CO	NO _x	VOC	CO	NO _x	VOC	CO	NO _x	VOC
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.0021	0.00962	0.0007	0.019	0.07022	0.0019	0.0007	0.00302	0.000028
Throughput [T] (tonnes / year)									
Emission = [EF] * [T] * 1000 (kg / year)									

* Source: E&P Forum, 1994.

Table 17: Calculation Worksheet for Emissions of PM₁₀ and Organics from Associated Gas Combustion

	PM ₁₀	Benzene	Toluene	Xylenes	PAH's	Formaldehyde	Acetaldehyde
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.0001216	3.36 x 10 ⁻⁸	5.44 x 10 ⁻⁸			1.2 x 10 ⁻⁶	
Throughput [T] (tonnes of assoc gas / year)							
Emission = [EF] * [T] * 1000 (kg / year)							

* Source: USEPA, 1995b (Adapted – see Section 5.7)

Table 18: Calculation Worksheet for Emissions of PM₁₀ and Organics from Non-Associated Gas Combustion

	PM ₁₀	Benzene	Toluene	Xylenes	PAH's	Formaldehyde	Acetaldehyde
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.000152	4.2 x 10 ⁻⁸	6.8 x 10 ⁻⁸			1.5 x 10 ⁻⁶	
Throughput [T] (tonnes of non-assoc gas / year)							
Emission = [EF] * [T] * 1000 (kg / year)							

* Source: USEPA, 1995b (Adapted – see Section 5.7)

Table 19: Calculation Worksheet for Emissions of PM₁₀ and Organics from Diesel Combustion (less than 600 hp)

	PM ₁₀	Benzene	Toluene	Xylenes	PAH's	Formaldehyde	Acetaldehyde
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.00613	1.847 x 10 ⁻⁵	8.082 x 10 ⁻⁶	5.635 x 10 ⁻⁶	3.318 x 10 ⁻⁶	2.341 x 10 ⁻⁵	1.518 x 10 ⁻⁵
Throughput [T] (tonnes of diesel / year)							
Emission = [EF] * [T] * 1000 (kg / year)							

* Source: USEPA, 1995b (Adapted – see Section 5.7)

Table 20: Calculation Worksheet for Emissions of PM₁₀ and Organics from Diesel Combustion (greater than 600 hp)

	PM ₁₀	Benzene	Toluene	Xylenes	PAH's	Formaldehyde	Acetaldehyde
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.00113	1.529 x 10 ⁻⁵	5.553 x 10 ⁻⁶	3.812 x 10 ⁻⁶	< 4.188 x 10 ⁻⁶	1.565 x 10 ⁻⁶	4.976 x 10 ⁻⁷
Throughput [T] (tonnes of diesel / year)							
Emission = [EF] * [T] * 1000 (kg / year)							

* Source: USEPA, 1995b (Adapted – see Section 5.7)

Table 21: Calculation Worksheet for Emissions of Metals from Diesel Combustion

	Metals												
	As	Be	Cd	Cr (VI)	Cu	Pb	Hg	Ni	Co	Mn	Se	Zn	F
Emission Factor [EF]* (tonnes emissions/tonnes throughput)	8.31x10 ⁻⁸	4.45x10 ⁻⁸	2.18x10 ⁻⁷			1.76x10 ⁻⁷	5.93x10 ⁻⁸	3.55x10 ⁻⁷		2.76x10 ⁻⁷			
Throughput [T] (tonnes / year)													
Emission = [EF] * [T] * 1000 (kg / year)													

* Source: USEPA, 1995b (Adapted – see Section 5.7)

Table 22: Calculation Worksheet for Emissions of Metals from Associated Gas Combustion

	Metals												
	As	Be	Cd	Cr (VI) ^(a)	Cu	Pb	Hg	Ni	Co	Mn	Se	Zn	F
Emission Factor [EF]* (tonnes emissions/tonnes throughput)	3.2x10 ⁻⁹	1.92x10 ⁻¹⁰	<1.76x10 ⁻⁸	1.12x10 ⁻⁹	1.36x10 ⁻⁹	4.34x10 ⁻⁹	4.16x10 ⁻⁹	3.36x10 ⁻⁸	1.344x10 ⁻⁹	6.08x10 ⁻⁹	<3.84x10 ⁻¹⁰	4.64x10 ⁻⁷	
Throughput [T] (tonnes / year)													
Emission = [EF] * [T] * 1000 (kg / year)													

* Source: USEPA, 1995b (Adapted – see Section 5.7), except for (a), from FIRE, 1997 (Adapted – see Section 5.7)

Table 23: Calculation Worksheet for Emissions of Metals from Non-Associated Gas Combustion

	Metals												
	As	Be	Cd	Cr (VI) ^(a)	Cu	Pb	Hg	Ni	Co	Mn	Se	Zn	F
Emission Factor [EF]* (tonnes emissions/tonnes throughput)	4.0x10 ⁻⁹	2.4x10 ⁻¹⁰	2.2x10 ⁻⁸	1.4x10 ⁻⁹	1.7x10 ⁻⁹	5.425x10 ⁻⁹	5.2x10 ⁻⁹	4.2x10 ⁻⁸	1.68x10 ⁻⁹	7.6x10 ⁻⁹	4.8x10 ⁻¹⁰	5.8x10 ⁻⁷	
Throughput [T] (tonnes / year)													
Emission = [EF] * [T] * 1000 (kg / year)													

* Source: USEPA, 1995b (Adapted – see Section 5.7), except for (a), taken from FIRE, 1997 (Adapted – see Section 5.7)

Table 24: Calculation Worksheet for Total N and Total P in Wastewater Flows*

NPI Substance	Average No. of Personnel in Facility over period [N]	Length of period [T] (days)	Emission Factors [E _f] (kg / person / day)	Emission of substance [E _{NP}] N * T * E _f (kg)
Total Nitrogen			0.0110	
Total Phosphorus			0.0025	

* Considers Total N and Total P emissions from facility population only.
Derived from West Australian Water Corporation wastewater treatment facility design criteria.

5.0 Assumptions

5.1 Produced Formation Water (PFW)

While a generic PFW (developed by APPEA) is detailed in Table 2, it must be recognised that this data should only be used in situations where facility specific PFW data is not available.

The composition of PFW is highly field specific, and will change over the lifetime of the reservoir. The use of a generic PFW in the estimation of emissions is likely to introduce a significant uncertainty in to the calculations.

5.2 Storage Tank Emissions

Table 5 presents VOC emission factors for fugitive and storage tanks. These emission factors have been developed by APPEA as part of its Greenhouse Gas Inventory.

Alternative EETs are available for the characterisation of these emissions (included in the *EET Manual for Fuel & Organic Liquid Storage*). The APPEA emission factors were selected as they present a simple approach to the estimation of these emissions, and have been specifically developed for the Australian oil and gas exploration and production industry.

5.3 Sources of Information

A wide range of data was reviewed in the development of this Manual, and that deemed most applicable to the oil and gas exploration and production industry has been used. Generally, E&P Forum data has been used in preference to other sources, except where either no data is available, or where an alternate source, (eg. AP42 or API), or data that more accurately represents the environmental performance of the industry has been provided.

5.4 Emission Factors

The available data on NPI substances in the literature is not uniform, with more detail being available for some substances and sources than for others.

For example, extensive data is available relating to the combustion of fuels. Factors have been taken from specific sources based on their applicability to oil and gas production and exploration. While data was not found for some NPI substances in the available literature (eg see shaded areas in Tables 17, 18, 21 and 22), this does not mean that the substance is not emitted by the oil and gas industry. It is the responsibility of each operator to identify the NPI substances for which reporting is required and subsequently, to quantify the emissions of the relevant substances.

5.5 Facility Specific Factors

This manual does not take account of facility specific upgrades, cleaner technologies, or emission reduction programs employed. Where applicable, the effectiveness of upgrades and emission reduction programs should be determined, and factored into any emission

estimations. The effectiveness of techniques may be determined with reference to:

- manufacturer's specifications;
- engineering calculations; and
- facility monitoring programs.

The effectiveness of these emission reduction initiatives can be factored into emissions estimation by including a proportional factor based on an assumed control efficiency, as detailed below:

$$[1 - (E_r/100)]$$

Where: E_r = overall emission reduction efficiency, %.

This would be applied to an emission factor as shown below:

$$E_{kpy,i} = [A * OpHrs] * EF_i * [1 - (CE_i/100)]$$

where :

$E_{kpy,i}$	=	emission rate of pollutant i, kg/yr
A	=	activity rate, t/hr
$OpHrs$	=	operating hours, hr/yr
EF_i	=	uncontrolled emission factor of pollutant i kg/t
CE_i	=	overall control efficiency for pollutant i, %

For processes where retro-fitting and continual improvement of emission controls have been carried out, the combined effectiveness of all emission reduction methods should be accounted for when characterising emissions for the purposes of NPI reporting. Where 'effectiveness factors' are used, these should be stated in all reports with the justification for their use. You should note that any modifications or changes to the default emission factors provided in this Manual require the consent of your relevant environmental authority.

5.6 Flaring

The emission factors for gas flaring presented in Section 4.2.1 assume a gas composition of 70% CH₄, 30% VOC w/w. However, vented gas composition varies depending on the type of facility, and emission factors should be modified using actual composition if this information is known.

Vent gas compositions, for example, include (E&P Forum, 1994):

- UK oil production platform 51% CH₄, 49% VOC w/w
- UK gas production platforms 92% CH₄, 8% VOC w/w
- Norway inventory assumed a composition of 65% CH₄, 35% VOC by volume

5.7 Conversion of Units

For combustion, the E&P Forum expresses emission in terms of tonnes emission / tonne. These emission factors may be converted to kg/m³ where the density of the combusted material is known.

Using the assumed densities below, a conversion factor was calculated to convert the E&P Forum data to metric units (Source: E&P Forum, 1994).

	Density
Diesel	0.85 te /m ³
Associated gas*	1 te/1000sm ³
Non-associated gas*	0.8 te/1000sm ³

*Associated gas is the gas produced from an oil and gas extraction operation, while non-associated gas is the gas from a well that only produces gas.

While standard cubic metres (sm³) are referred to in the E&P documentation, it is understood that facilities generally report emission as cubic metres (m³) rather than sm³ (Source: PPK, 1998). Therefore, all sm³ units are assumed to be equal to m³ units.

Standard Cubic Metres relates to the volume of gas at 'standard' conditions. To convert to cubic metres site-specific characteristics must be known and applied to the calculation shown below.

$$V_F = \frac{V_S P_S T_F}{T_S P_F}$$

Where:

V _S	=	Volume at 'standard' conditions, sm ³
P _S	=	Standard pressure, 101.326 kPa
T _S	=	Standard temperature, 288 deg Kelvin
V _F	=	Volume at facility conditions, m ³
P _F	=	Pressure at facility conditions
T _F	=	Temperature at facility conditions

Conversion of units cited in USEPA, (1995b) documentation have used conversion factors stated in the text. However, when converting MMBtu to other units, it must be appreciated that MMBtu is equivalent to 10⁶ Btu not 10¹² Btu.

6.0 Definitions

Reference should be made to the NEPM for the National Pollution Inventory and *The NPI Guide* for definition of terms used within the NPI system.

<i>Associated Gas</i>	Gas produced from an oil and gas extraction operation.
<i>Non-Associated Gas</i>	Gas from a well that only produces gas.
<i>Direct Measurement</i>	Technique used to estimate emissions to the environment through the sampling and analysis of emission streams.
<i>Emission</i>	Any release of substances to the environment, whether it is in a pure form, or contained in other matter. Emissions may be solid, liquid, or gaseous.
<i>Emission Factor</i>	A number or equation that may be applied to raw data from a facility to estimate emissions from that facility without the need for emissions sampling and analysis. This technique is most often used to estimate gaseous emissions to the environment.
<i>Flaring</i>	Combustion of waste, or surplus gases via stack.
<i>Fugitive Emissions</i>	Emissions not released from a vent or stack.
<i>Inventory</i>	Means of recording usage and stores of all materials and product held on a facility, or utilised by a process.
<i>Loading Losses</i>	Emissions resulting from the transfer of product to non-pipeline transportation methods, such as rail, trucks, or tankers..
<i>Mass Balance Technique</i>	Estimation of emissions to the environment through the equalisation of inputs and outputs to a particular process or facility.
<i>Power Generation</i>	Production of power for the operation of facilities, and use in processes.
<i>Produced Formation Water (PFW)</i>	Water produced from the formation with the crude oil, that is separated, treated and disposed of either to surface waters, or through reinjection to the formation.
<i>Production Testing</i>	Testing activities associated with exploration activities to determine the viability of a well.
<i>Venting</i>	Non-combusted emissions released from non-machinery sources, such as the release of waste gas, or volatilisation from crude oil storage tanks

7.0 References

7.1 References Cited in Text

API (1996), *Calculation Workbook for Oil and Gas Production Equipment Fugitive Emissions*, API Publication 4638

APPEA (1997), *Greenhouse Gas Emissions and Action Plans from the Australian Petroleum Exploration and Production Industry 1990-1995, Report to the Greenhouse Challenge Program*, 8 August 1997

APPEA (1998), *Letter from Barry Jones (APPEA) to Rory Sullivan (NSW EPA)*, 29 September 1998

E&P Forum (1994), *Methods for Estimating Atmospheric Emissions from E & P Operations, Report no. 2.59/197*

Emission Inventory Improvement Programme (1997), *Introduction to Stationary Point Source Emission Inventory Development, Volume II*, Eastern Research Group Inc.

PPK (1998), E-mail from Steve Marlborough (PPK) to Rory Sullivan (NSWEPA) re E&P Forum Data, 13 October 1998, 16.58.

USEPA (1995a), *Protocol for Equipment Leak Emission Estimates, EPA -453/R-95-017*

USEPA (1995b), *Compilation of Air Pollutant Emission Factors, Volume I, Fifth Edition, AP-42*

FIRE (1997), *Factor Information Retrieval System (Air Chief CD ROM, Version 5.0, USEPA*

The following Emission Estimation Technique Manuals referred to in this Manual can be obtained from your local environmental authority.

- Emission Estimation Technique Handbook for Petroleum Refineries
- Emission Estimation Technique Manual for Sewage and Wastewater Treatment
- Emission Estimation Technique Manual for Fuel & Organic Liquid Storage

7.2 References Not Cited in Text

APPEA (1994), *The Findings of an Independent Scientific Review*, Edited by Swan, Neff, Young, Australian Petroleum Production & Exploration Association.

API, 1993a, *Estimation of Aromatic Hydrocarbon Emissions from Glycol Dehydration Units using a Process Simulation Model, DR110*

API (1993b), *Fugitive Hydrocarbon Emissions from Oil and Gas Production Operations*, API Publication 4589

API (1995a), *Emission Factors for Oil and Gas Production Operations*, API Publication 4615

API (1995b), *Potential BTEX Emissions from the Nations Triethylene Glycol Units in Oil and Natural Gas Facilities, DR220*

BP (1997), *Environmental Performance - Group Reporting Guidelines, Version 1.0*

E&P Forum (1994a), *North Sea Produced Water: Fate and Effects in the Marine Environment, Report no. 2.62/204*

Appendix A

Example Emissions Calculations

This Appendix provides example calculations for specific emissions. The Appendix is intended to provide guidance on the estimation of emissions from a range of sources. It must be noted that total facility emissions are estimated by calculating emissions from individual sources, and then adding each of these estimates for a cumulative total.

A1 Combustion

A facility uses diesel-fired engines, and gas fired turbines and heaters.

Annual fuel usage is:

- Engines : 303 tonnes of diesel
- Turbines : 8,346 tonnes of gas
- Heaters : 135 tonnes of gas

To calculate carbon monoxide emissions from combustion at the facility, the annual fuel use is multiplied by the relevant emission factor (Table 15 & 16) to give the annual emission of CO from that source:

	Engines	Turbines	Heaters	Total Combustion CO Emissions
Emission Factor [EF]* (tonnes emissions/ tonnes throughput)	0.019	0.0027	0.0008	
Throughput [T] (tonnes / year)	303	8,346	135	
Emission = [EF] * [T] * 1000 (kg / year)	5,757	22,534	108	28,399 kg

A2 Fugitive Emissions (using Method 2 as described in Section 4.2.1)

A review of facility equipment types is carried out and an inventory developed as shown below:

Valves	1000
Open-ended lines	500
Pump Seals	600
Connectors	560
Flanges	230
Others	430

Of the 1000 valves:

- 500 are in gas service:
- 350 are in oil service; and
- 150 are in water/oil service

Of the 500 valves in gas service, it is ascertained that 100 valves are, on average, 90 weight percent TOCs and 10 percent water vapour, and it is estimated that these valves operate for 7400 hours per year.

The gas service emission factor for valves of 4.5×10^{-3} kg/hr/source (Table 6) is applied to the calculation and emissions are estimated with the following parameters:

Source of Fugitive Emission	(N) No. Pieces of Equipment	(W _{TOC}) Average Weight Fraction	(F _A) Average Emission Factor - Table 6 -	(E _{TOC}) Emission Rate of TOC = (F _A * W _{TOC} * N)
Valves - gas service	500	0.9	4.5×10^{-3}	2.025

Speciated fraction for valves - gas service	E _{TOC} (kg TOC/hr)	(HRS) Hours of Operation (hrs / year)	(SF) Speciation Factor - Table 8 -	[E _{SF}] Speciated Substance Emission = (E _{TOC} * HRS * SF) (kg / year)
VOC	2.025	7400	0.171	2562.4
n-hexane (a)	2.025	7400	0.00693	103.8
Benzene	2.025	7400	0.00069	10.3
Toluene	2.025	7400	0.00038	5.7
Ethylbenzene	2.025	7400	0.00003	0.4
Xylenes	2.025	7400	0.00009	1.3

This process would be carried out for all component streams at the facility, providing a facility-wide fugitive emission estimate.

A3 Venting

Assuming that each year, 4,024,500 tonnes of light crude oil are loaded to ships (tankers), the total VOC emissions from this activity would be estimated by multiplying the volume loaded, by the emission factor from Table 11.

	Ship Loading Losses
	VOC
Emission Factor* [EF] (tonnes emissions/ tonnes throughput)	0.0001
Throughput [T] (tonnes / year)	4,024,500
Emission = [EF] * [T] * 1000 (kg / year)	402,450

VOC emissions may be speciated using the light oil speciation factors from Table 8:

Speciation Substance	VOC Emission	Speciation Factor	Speciated Emission (kg / year)
n-hexane	402,450	0.023	9256
Benzene	402,450	0.00121	487
Toluene	402,450	0.00105	423
Ethylbenzene	402,450	0.00016	64
Xylenes	402,450	0.00033	133

These emission estimates would then be added to the total facility emission of the NPI substance.