National Pollutant Inventory

Emission Estimation Technique Manual

for

Gas Supply

EMISSION ESTIMATION TECHNIQUES
FOR
GAS SUPPLY

TABLE OF CONTENTS

GAS SUPPLY

LIST OF FIGURES, TABLES AND EXAMPLES

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 the gas supply industry.

EET MANUAL:	Gas Supply
HANDBOOK:	Gas Supply
ANZSIC CODES:	3620

Pacific Air & Environment Pty Ltd drafted this Manual on behalf of Environment Australia. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders. Particular thanks are due to the Australian Gas Association and its members for their assistance in the development of this Manual.

1.1   Manual Structure

This Manual is structured as follows:

- **Section 2.0** provides a brief overview of the gas supply industry.
- **Section 3.0** summarises the NPI-listed substances, which are triggered, or likely to be triggered, for the gas supply industry. Category 1, 2 and 3 substances are discussed in **Sections 3.1.1, 3.1.2** and **3.1.3** respectively. **Sections 3.2, 3.3** and **3.4** detail the expected emissions to air, water and land respectively from the industry. These sections also describe the sources of these emissions and where emission estimation techniques for each of these sources are to be found.
- **Section 4.0** provides a glossary of technical terms and abbreviations used in this Manual.
- **Section 5.0** provides a list of references used in the development of this Manual.
- **Appendix A** provides an overview of the four general types of emission estimation techniques: sampling or direct measurement; mass balance; engineering calculations and emission factors, as well as example calculations to illustrate their use. Reference to relevant sections of this appendix is recommended in understanding the application of these techniques with particular respect to the gas supply industry.
- **Appendix B** provides a discussion of the reliability and uncertainty associated with each of the techniques presented in **Appendix A.**
- **Appendix C** provides a list of variables and symbols used throughout this Manual.

1.2   Manual Application

Context and use of this Manual

This NPI Manual provides a 'how to' guide for the application of various methods to estimate emissions as required by the NPI. It is recognised that the data that is generated in this process will have varying degrees of accuracy with respect to the actual emissions from gas supply facilities. In some cases there will necessarily be a large potential error due to inherent assumptions in the various emissions estimation techniques (EETs).

EETs should be considered as 'points of reference'

The EETs and generic emission factors presented in this Manual should be seen as 'points of reference' for guidance purposes only. Each has associated error bands that are potentially quite large. Appendix B discusses the general reliability associated with the various methods. The potential errors associated with the different EET options should be considered on a case-by-case basis as to their suitability for a particular facility. Facilities may use EETs that are not outlined in this document. They must, however, seek the consent of their relevant environmental authority to determine whether any 'in house' EETs are suitable for meeting their NPI reporting requirements.

Hierarchical approach recommended in applying EETs

This Manual presents a number of different EETs, each of which could be applied to the estimation of NPI substances. The range of available methods should be viewed as a hierarchy of available techniques in terms of the error associated with the estimate. Each substance needs to be considered in terms of the level of error that is acceptable or appropriate with the use of the various estimation techniques. Also, the availability of pre-existing data and the effort required to decrease the error associated with the estimate will need to be considered. For example, if emissions of a substance are clearly very small, no matter which EET is applied, then there would be little gained by applying an EET which required significant additional sampling.

The steps in meeting the reporting requirements of the NPI can be summarised as follows:

Category 1 and 1a Substances:

Identify which reportable NPI substances are used (or handled by way of their incidental presence in ore or materials, or exceeds the bulk storage capacity for 1a), and determine whether the amounts used or handled are above the 'threshold' values and therefore trigger reporting requirements. See **Section 3.1.1** of this Manual for guidance on which Category 1 substances are likely to require reporting in the gas supply industry.

Category 2a and 2b Substances:

Determine the amount and rate of fuel (or waste) burnt each year, the annual power consumption and the maximum potential power consumption, and assess whether the threshold limits are exceeded. See **Section 3.1.2** of this Manual for a discussion of which Category 2 substances are likely to be triggered in the gas supply industry.

Category 3 Substances:

Determine the annual emissions to water and assess whether the threshold limits are exceeded. It is unlikely that this NPI Category will require reporting for the gas supply industry.

Those substances above the threshold values

Examine the available range of EETs and determine emission estimates using the most appropriate EET.

Generally, it will be appropriate to consider various EETs as alternative options whose suitability should be evaluated in terms of:

- the associated reliability or error bands; and
- the cost/benefit of using a more reliable method.

The accuracy of particular EETs is discussed in **Appendix B**.

NPI emissions in the environmental context

It should be noted that the NPI reporting process generates emission estimates only. It does not attempt to relate emissions to potential environmental impacts, bioavailability of emissions or natural background levels.

2.0   Processes and Emissions

This Manual will cover the gas supply industry as defined under the ANZSIC Code 3620-Gas Supply. These operations include distribution of manufactured town gas, natural gas or liquefied petroleum gas (LPG). Discussion with the gas industry indicated that, at the time of writing, town gas was no longer produced in Australia for gas supply. It should also be noted that the major difference between gas and LPG, in the context of this Manual, is that LPG distribution through the mains system does not include high pressure transmission (as is the case for natural gas). LPG is distributed from LPG vessels that are filled periodically by road tankers. The treatment of natural gas is not covered under this ANZSIC code.

In very simple terms, 'transmission' represents the high-pressure transfer of gas, using compressors, from the point of production to the city gate. 'Distribution' involves the remaining transport of the gas from the city gate (high pressure) to the customer (low pressure). Figure 1 gives an overview of the gas supply system. Emissions of concern with respect to the NPI are total VOCs and hydrogen sulfide released through losses in the piping systems. These losses are to be reported as aggregated emissions under the NPI. Some natural gas transmission systems include gas compressors. In these systems, there will also be NPI-listed releases as a result of gas combustion (to power the compressors).
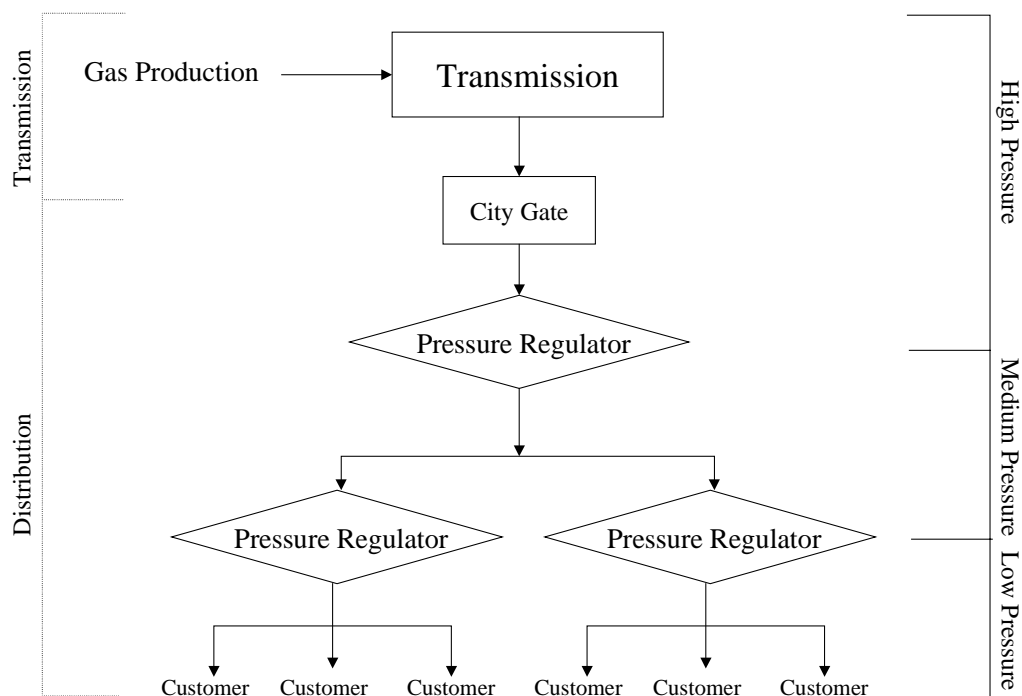

Figure 1 - Gas Supply System - Overview

3.0   Reportable Emission Sources

3.1   Reporting Thresholds

3.1.1   Category 1

From discussions with industry and a review of the published data on gas composition it is likely that the only substance present in sufficient quantities to trigger the Category 1 reporting threshold of 10 tonnes per annum is hydrogen sulfide (AGL, 1995). In addition, the Category 1a threshold of 25 tonnes per annum for volatile organic compounds (VOCs) will also be triggered.

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, even if the actual emissions of the substances are very low or zero.

3.1.2   Category 2

The Category 2 threshold is based on energy consumed or on fuel use. The Category 2a threshold for fuel usage is triggered if:

- a facility burns 400 tonnes or more of fuel or waste per year; or
- a facility burns 1 tonne or more of fuel or waste per hour.

The Category 2b threshold is triggered if:

- a facility burns 2000 tonnes or more of fuel or waste per year; or
- a facility uses 60 000 megawatt hours (MWh) or more of energy in a year; or
- a facility's maximum potential power consumption is rated at 20 megawatts (MW) or more at any time during the year.

From discussions with industry, the combustion of gas in the gas-fired compressors that form part of the gas transmission and distribution system may lead to reporting on Category 2 substances being triggered.

The fuel consumption required to trigger the Category 2 thresholds may be found in Table 1.

Table 1 - Approximate Fuel Usage Required to Trigger Category 2 Thresholds

Fuel Type	Category 2a	Category 2b
Natural Gas[a]	$5.30 * 10^5$ m^3 per reporting year, or at least $1.32 * 10^3$ m^3 in any one hour in the reporting year	$2.65 * 10^6$ m^3 per reporting year

[a]Assuming ideal gas with a density of 0.755 kg/m^3 at 15°C and 101.325 kPa. Natural gas (NSW) data from the *Natural Gas Technical Data Handbook* (AGL Gas Company (NSW) Limited, 1995)

Discussions with the industry indicate that the maximum compressor size used in the Australian gas transmission system is 10 MW and that compressors are only run

periodically. The following example illustrates the calculation procedure for determining if a Category 2 threshold has been exceeded. It is likely that some operators will trigger the Category 2a threshold but it is unlikely that any will trigger the Category 2b threshold.

Example 1 - Category 2 Threshold Calculations

What is the minimum power rating for compressors that will trigger the hourly Category 2a threshold (of 1 tonne per hour or 1000 kg/hr)?

Assume a turbine efficiency of 45%.

Gross heating value of natural gas	=	38.8 MJ/m³ (AGL, 1995)
Density	=	0.755 kg/m³ (AGL, 1995)

Volume required to trigger	=	Threshold value / Density
	=	1000 kg/hr / 0.755kg/m³
	=	1324 m³/hr

Turbine Power	=	Heating Value * Volume * Efficiency
	=	38.8 MJ/m³ * 1324 m³/hr * 0.45
	=	23 126 MJ/hr
	=	6.42 MW

Therefore, if the turbine has a power rating of 6.42 MW or greater, then the Category 2a reporting threshold will be exceeded (and, as a consequence, reporting will be required for Category 2a substances).

If a facility triggers the Category 2a threshold, all Category 2a pollutants need to be reported. If a facility triggers the Category 2b threshold, all Category 2b pollutants need to be reported, in addition to Category 2a substances. Category 2 substances are listed in Table 2.

Table 2 - NPI-listed Category 2 Substances

Category 2a Substances	Category 2b Substances
Carbon Monoxide	Arsenic & compounds
Fluoride Compounds	Beryllium & compounds
Hydrochloric Acid	Cadmium & compounds
Oxides of Nitrogen	Chromium (III) compounds
Particulate Matter (PM_{10})	Chromium (VI) compounds
Polycyclic Aromatic Hydrocarbons	Copper and compounds
Sulfur Dioxide	Lead & compounds
Total Volatile Organic Compounds	Magnesium Oxide Fume
	Manganese & compounds
	Mercury & compounds
	Nickel & compounds
	Nickel Carbonyl
	Nickel Subsulfide
	Polychlorinated Dioxins & Furans
	PLUS all Category 2a substances

3.1.3   Category 3

Category 3 substances involve the release of nutrients (phosphorus and nitrogen) to surface waters. This is unlikely to be an issue in the gas supply industry and no reporting of Category 3 substances is expected to be required.

3.2   Emissions to Air

Total VOCs, hydrogen sulfide and Category 2 substances are the only likely substances to require reporting by the gas supply industry under the NPI.

VOCs and Hydrogen Sulfide

VOCs and hydrogen sulfide are released through line losses and through blowdown operations.   From discussions with the gas supply industry, industry blowdown operations generally no longer involve venting to atmosphere. However, if natural gas is vented to atmosphere, the quantities of gas vented are recorded for billing purposes. These estimated quantities may be used as the basis for NPI reporting.

Emissions as a consequence of line losses can be estimated using the measured line losses (also metered for billing purposes) and the concentrations in the gas stream. Example 2 illustrates how these data may be applied for the purposes of emissions estimation. Calculating emissions based on measured losses can be applied to both transmission (for natural gas) distribution systems (for both natural gas and LPG). It should be noted that most of the LPG distribution systems in Australia are relatively new and, as a consequence, there should be negligible losses due to routine operations. It is likely that it is only accident situations (eg. burst pipes) which would lead to significant emissions of NPI-listed substances.

Unaccounted for gas (UAFG) consists of line losses and metering errors. To estimate line losses, it can be conservatively assumed that all UAFG is line loss. Industry literature indicates that currently UAFG is 2.5% within the Australian gas industry (AGA, 1998b).

Example 2 - Hydrogen Sulfide Emission Calculations

A gas distribution company supplies 70PJ of natural gas to its customers per year. The company has an UAFG value of 2%. Gas supplied to the distributor has a hydrogen sulfide concentration of 2.5 mg/m^3 at STP. Estimate the quantities of total VOCs and hydrogen sulfide emitted.

Assume (conservatively) that all UAFG is losses.

Convert energy value to an equivalent volume of gas:

Gross heating value of natural gas	= 38.8 MJ/m^3 (AGL,1995)
Equivalent volume of gas	= Energy supplied / Heating value
	= 70 PJ/yr / 38.8 MJ/m^3 * 10^9 MJ/PJ
	= 1.804 * 10^9 m^3 at STP/yr
Volume lost (emitted)	= 2% of Equivalent volume
	= 0.02 * 1.804 * 10^9 m^3 at STP/yr
	= 3.608 * 10^7 m^3 at STP/yr

Estimate VOC emissions:

Total organic compounds (including methane) present in natural gas
= 96.8% (AGL, 1995)

If the methane content of natural gas is 90% (typical level)

Volume of VOC	= 6.8% of Volume lost
	= 2.454 * 10^6 m^3 at STP/yr
Density of gas	= 0.755kg/m^3 (assumed to be the same as natural gas. (AGL, 1995))
Mass of VOC released	= Volume * Density
	= 2.454 * 10^6 m^3/yr * 0.755kg/m^3
	= 1.853 * 10^6 kg/yr
	= 1 853 tonnes/yr

Estimate H$_2$S emissions:

Concentration of H$_2$S	= 2.5mg/m^3
Mass of H$_2$S emitted	= Concentration * Volume lost
	= 2.5mg/m³ * 3.608 * 10^7 m^3 at STP/yr
	= 90 200 000mg/yr
	= 90.2 kg/yr

Therefore, the amounts to be reported would be 1853 tonnes/yr of VOC and 90.2 kg/yr of hydrogen sulfide.

Category 2 substances

Category 2 substances will be released from on-site combustion (eg. to generate power for the compressors). Refer to the *Emission Estimation Technique Manual for Combustion Engines* for a discussion on how to estimate these emissions.

3.3   Emissions to Water

It is extremely unlikely that any reporting on emissions to water would be required for the gas supply industry.

3.4   Emissions to Land

It is extremely unlikely that any reporting on emissions to land would be required for the gas supply industry.

Under the NPI, the following are classed as transfers and are not required to be reported:

- discharges of substances to sewer or tailings dam;
- deposit of substances to landfill; and,
- removal of substances from a facility for destruction, treatment, recycling, reprocessing, recovery, or purification.

The definition of transfer has been clarified by the NPI Implementation Working Group as:

"All emissions of listed substances, except those which are directed to, and contained by, purpose built facilities, are to be reported to the NPI. This applies irrespective of whether the substances' fate is within or outside a reporting facility boundary. With respect to receipt of NPI-listed substances, such receiving facilities are to be operating in accordance with any applicable State or Territory government requirements."

Solid wastes, slurries, sediments and spilled materials may contain NPI-listed substances. It is expected that all of these substances will be sent to sewer, sent offsite for treatment or recycling or sent to landfill. As a consequence, there will be no requirement to report on these emissions. Therefore, it is likely that the only reporting requirements for the industry will relate to the following releases to land:

- spills or accidental releases to land (if spills occur, see the *EET Manual for Fugitive Emissions* for guidance on how to estimate these releases);
- releases to groundwater; and
- on-site disposal where the on-site disposal does not meet the definition provided above.

4.0   Glossary of Technical Terms and Abbreviations

AGL   The Australian Gas Light Company. Commonly referred to as AGL.

ANZSIC   Australian and New Zealand Standard Industrial Classification

CEMS   Continuous Emission Monitoring System

CO   Carbon Monoxide

CO_2 Carbon Dioxide

EET   Emission Estimation Technique

EFR   Emission Factor Rating

LPG   Liquefied Petroleum Gas

NEPM   National Environment Protection Measure

NO_x Oxides of Nitrogen

NPI   National Pollutant Inventory

PM_{10} Particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less (ie. $\leq 10\mu m$)

SO_2 Sulfur Dioxide

STP   Standard Temperature and Pressure ($0^{\circ}C$ and 101.325 kPa)

Transfer   Transfers consist of a deposit of a substance into landfill, or discharge of a substance to a sewer or tailings dam, or removal of a substance from a facility for destruction, treatment, recycling, reprocessing, recovery or purification (*NEPM*, Clause 3(3)). Emissions classed as transfers are not required to be reported under the NPI.

TSP   Total Suspended Particulate

UAFG   Unaccounted for gas – Consisting of line losses and metering errors

USEPA   United States Environmental Protection Agency

VOC   Volatile Organic Compounds

5.0   References

AGA, 1998a.   *Research Paper No. 8 - Gas Transmission Pipelines*, The Australian Gas Association, Canberra, ACT, 2601.

AGA, 1998b.   *Research Paper No. 9 - Gas Distribution and Retailing*, The Australian Gas Association, Canberra, ACT, 2601.

AGL Gas Company (NSW) Limited, 1995, *Natural Gas Technical Data Book*, Industrial Applications Department - AGL Gas Company (NSW) Limited, Five Dock, Australia.

ANZSIC: Australian and New Zealand Standard Industrial Classification, Australian Bureau of Statistics & NZ Dept of Statistics 1993, ABS Catalogue No 1292.0.

USEPA. 1997. *Emission Factor Documentation for AP-42*. United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.
http://www.epa.gov/ttn/chief/ap42.html

The following EET Manuals are available at the NPI Homepage (http://www.environment.gov.au/net/npi.html), and from your local Environmental Protection Authority:

- *Emission Estimation Technique Manual for Combustion Engines;* and
- *Emission Estimation Technique Manual for Fugitive Emissions.*

Appendix A - 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; and
- emission factors.

Select the EETs (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 EETs 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 handbook 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.**

You should note that the EETs presented or referenced 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.

A list of the variables and symbols used in this Manual may be found in **Appendix C**.

A.1   Direct Measurement

You may wish to undertake direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements. However, the NPI does not require you to undertake additional sampling and measurement. For the sampling data to be adequate and able to be used for NPI reporting purposes, it would need to be collected over a period of time, and to be representative of operations for the whole year.

A.1.1 Sampling Data

Stack sampling test reports often provide emissions data in terms of kg per hour or grams per cubic metre (dry). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

An example of test results is summarised in Table 3. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of the test run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in m^3/s. The filter weight gain is determined gravimetrically and divided by the volume of gas sampled, as shown in Equation 1 to determine the PM concentration in grams per m^3. Note that this example does not present the condensable PM emissions.

Pollutant concentration is then multiplied by the volumetric flow rate to determine the emission rate in kilograms per hour, as shown in Equation 2 and Example 3.

Equation 1

$$C_{PM} \quad = \quad C_f \ / \ V_{m, STP}$$

where:

C_{PM} = concentration of PM or gram loading, g/m^3
C_f = filter catch, g
$V_{m,STP}$ = metered volume of sample at STP, m^3

Equation 2

$$E_{PM} = C_{PM} * Q_d * 3.6 * [273 / (273 + T)]$$

where:

E_{PM}	=	hourly emissions of PM, kg/hr
C_{PM}	=	concentration of PM or gram loading, g/m^3
Q_d	=	actual stack gas volumetric flow rate, m^3/s, dry
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
T	=	temperature of the gas sample, °C

Table 3 - Stack Sample Test Results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (sec)		7200	7200	7200
Moisture collected (g)	g_{MOIST}	395.6	372.6	341.4
Filter catch (g)	C_f	0.0851	0.0449	0.0625
Average sampling rate (m^3/s)		$1.67 * 10^{-4}$	$1.67 * 10^{-4}$	$1.67 * 10^{-4}$
Standard metered volume (m^3)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (m^3/s), dry	Q_d	8.48	8.43	8.45
Concentration of particulate (g/m^3)	C_{PM}	0.0718	0.0387	0.0537

Example 3 - Using Stack Sampling Data

PM emissions calculated using Equation 1 and Equation 2 (above) and the stack sampling data for Test 1 (presented in Table 3, and an exhaust gas temperature of 150°C (423 K)). This is shown below:

C_{PM}	=	$C_f / V_{m, STP}$
	=	0.0851 / 1.185
	=	0.072 g/m^3
E_{PM}	=	$C_{PM} * Q_d * 3.6 * [273/(273 + T)]$
	=	0.072 * 8.48 * 3.6 * (273/423 K)
	=	1.42 kg/hr

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use Equation 3 below to calculate the dry particulate emissions in kg/hr.

Equation 3

$$E_{PM} = Q_a * C_{PM} * 3.6 * (1 - moist_R/100) * [273/(273 + T)]$$

where:

E_{PM}	=	hourly emissions of PM in kilograms per hour, kg/hr
Q_a	=	actual (ie. wet) cubic metres of exhaust gas per second, m^3/s
C_{PM}	=	concentration of PM or gram loading, g/m^3
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
$moist_R$ =		moisture content, %
273	=	273 K (0°C)
T	=	stack gas temperature, °C

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM_{10} from total PM emissions, a size analysis may need to be undertaken. The weight PM_{10} fraction can then be multiplied by the total PM emission rate to produce PM_{10} emissions. Alternatively, it can be assumed that 100% of PM emissions are PM_{10}; ie. assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less ie. ≤10μm. In most situations, this is likely to be a conservative assumption, but it may be a suitable technique to obtain a reasonable characterisation of emissions for the purposes of NPI reporting.

To calculate moisture content use Equation 4.

Equation 4

Moisture percentage =   100 * weight of water vapour per specific volume of stack gas/ total weight of the stack gas in that volume.

$$moist_R = \frac{100 * \left(\frac{g_{moist}}{(1000 * V_{m,STP})}\right)}{\left(\frac{g_{moist}}{(1000 * V_{m,STP})}\right) + \rho_{STP}}$$

where:

$moist_R$ =		moisture content, %
g_{moist}	=	moisture collected, g
$V_{m,STP}$	=	metered volume of sample at STP, m^3
ρ_{STP}	=	dry density of stack gas sample, kg/m^3 at STP
		{if the density is not known a default value of 1.62 kg/m^3 may be used. This assumes a dry gas composition of 50% air, 50% CO_2}

Example 4 - Calculating Moisture Percentage

A 1.2m^3 sample (at STP) of gas contains 410g of water. To calculate the moisture percentage use Equation 4.

$$moist_R = \frac{100 * \frac{g_{moist}}{(1000 * V_{m,STP})}}{\frac{g_{moist}}{(1000 * V_{m,STP})} + \rho_{STP}}$$

$$
\begin{aligned}
g_{MOIST}/1000 * V_{m,STP} \quad &= \quad 410 \,/\, (1000 * 1.2) \\
&= \quad 0.342 \\
moist_R \quad &= \quad 100 * 0.342 \,/\, (0.342 + 1.62) \\
&= \quad 17.4\%
\end{aligned}
$$

A.1.2 Continuous Emission Monitoring System (CEMS) Data

A continuous emission monitoring system (CEMS) provides a continuous record of emissions over time, usually by reporting pollutant concentration. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas or liquid flow rate of that pollutant.

Although CEMS can report real-time hourly emissions automatically, it may be necessary to estimate annual emissions from hourly concentration data manually. This Section describes how to calculate emissions for the NPI from CEMS concentration data. The selected CEMS data should be representative of operating conditions. When possible, data collected over longer periods should be used.

It is important to note that, prior to using CEMS to estimate emissions, you should develop a protocol for collecting and averaging the data in order that the estimate satisfies the local environmental authority's requirement for NPI emission estimations.

To monitor SO_2, NO_x, VOC, and CO emissions using a CEMS, you use a pollutant concentration monitor that measures the concentration in parts per million by volume dry air (ppm_{vd} = volume of pollutant gas/10^6 volumes of dry air). Flow rates should be measured using a volumetric flow rate monitor. Flow rates estimated based on heat input using fuel factors may be inaccurate because these systems typically run with high excess air to remove the moisture out of the kiln. Emission rates (kg/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 4 presents example CEMS data output for three periods for a hypothetical furnace. The output includes pollutant concentrations in parts per million dry basis (ppm_{vd}), diluent (O_2 or CO_2) concentrations in percent by volume dry basis (%v, d) and gas flow rates; and may include emission rates in kilograms per hour (kg/hr). This data represents a snapshot of a hypothetical boiler operation. While it is possible to determine total emissions of an individual pollutant over a given time period from this data, assuming the CEMS operates properly all year long, an accurate emission estimate can be made by adding the hourly emission estimates if the CEMS data is representative of typical operating conditions.

Table 4 - Example CEMS Output for a Hypothetical Furnace Firing Waste Fuel Oil

Time	O_2 content	Concentration				Gas Flow Rate (Q)	Production Rate of Product (A)
	% by volume	SO_2 (ppm$_{vd}$)	NO_x (ppm$_{vd}$)	CO (ppm$_{vd}$)	VOC (ppm$_{vd}$)	m^3/s	tonnes/hour
1	10.3	150.9	142.9	42.9	554.2	8.52	290
2	10.1	144.0	145.7	41.8	582.9	8.48	293
3	11.8	123.0	112.7	128.4	515.1	8.85	270

Hourly emissions can be based on concentration measurements as shown in Equation 5.

Equation 5

$$E_i = (C * MW * Q * 3600) / [22.4 * ((T + 273)/273) * 10^6]$$

where:

E_i	=	emissions of pollutant i, kg/hr
C	=	pollutant concentration, ppm$_{v,d}$
MW	=	molecular weight of the pollutant, kg/kg-mole
Q	=	actual stack gas volumetric flow rate, m^3/s
3600	=	conversion factor, s/hr
22.4	=	volume occupied by one mole of gas at standard temperature and pressure (0°C and 101.3 kPa), m^3/kg-mole
T	=	temperature of gas sample, °C

Actual annual emissions can be calculated by multiplying the emission rate in kg/hr by the number of actual operating hours per year (OpHrs) as shown in Equation 6 for each typical time period and summing the results.

Equation 6

$$E_{kpy,i} = \Sigma (E_i * OpHrs)$$

where:

$E_{kpy,i}$	=	annual emissions of pollutant i, kg/yr
E_i	=	emissions of pollutant i, kg/hr (from Equation 5)
OpHrs	=	operating hours, hr/yr

Emissions in kilograms of pollutant per tonne of product produced can be calculated by dividing the emission rate in kg/hr by the activity rate (production rate (tonnes/hr) during the same period. This is shown in Equation 7 below.

It should be noted that the emission factor calculated below assumes that the selected time period (ie. hourly) is representative of annual operating conditions and longer time periods should be used for NPI reporting where they are available. Use of the calculation is shown in Example 5.

Equation 7

$$E_{kpt,i} \quad = \quad E_i / A$$

where:

$E_{kpt,i}$ =   emissions of pollutant i per tonne of product produced, kg/t
E_i =   hourly emissions of pollutant i, kg/hr
A   =   production, t/hr

Example 5 illustrates the application of Equation 5, Equation 6 and Equation 7.

Example 5 - Using CEMS Data

This example shows how SO_2 emissions can be calculated using Equation 5 based on the CEMS data for Time Period 1 shown in Table 4, and an exhaust gas temperature of 150°C (423 K).

$$
\begin{aligned}
E_{SO2,1} \quad &= \quad (C * MW * Q * 3600)/[(22.4 * (T + 273/273) * 10^6] \\
&= \quad (150.9 * 64 * 8.52 * 3600)/[22.4 * (423/273) * 10^6] \\
&= \quad 296\ 217\ 907/34\ 707\ 692 \\
&= \quad 8.53 \text{ kg/hr}
\end{aligned}
$$

For Time Period 2, also at 150°C
$E_{SO2,2}$ =   8.11 kg/hr

For Time Period 3, also at 150°C
$E_{SO2,3}$ =   7.23 kg/hr

Say representative operating conditions for the year are:

Period 1   =   1500 hr
Period 2   =   2000 hr
Period 3   =   1800 hr

Total emissions for the year are calculated by adding the results of the three Time Periods using Equation 6:

$$
\begin{aligned}
E_{kpy,SO2} \quad &= \quad E_{SO2,1} * OpHrs + E_{SO2,2} * OpHrs + E_{SO2,3} * OpHrs \\
&= \quad (8.53 * 1500) + (8.11 * 2000) + (7.23 * 1800) \text{ kg} \\
&= \quad 42\ 021 \text{ kg/yr}
\end{aligned}
$$

Emissions, in terms of kg/tonne of product produced when operating in the same mode as time period 1, can be calculated using Equation 7

$$
\begin{aligned}
E_{kpt,SO2} \quad &= \quad E_{SO2} / A \\
&= \quad 8.53 / 290 \\
&= \quad 2.94 * 10^{-2} \text{ kg } SO_2 \text{ emitted per tonne of product produced}
\end{aligned}
$$

When the furnace is operating as in time periods 2 or 3, similar calculations can be undertaken for emissions per tonne.

A.2   Using Mass Balance

A mass balance identifies the quantity of substance going in and out of an entire facility, process, or piece of equipment. Emissions can be calculated as the difference between input and output of each listed substance. Accumulation or depletion of the substance within the equipment should be accounted for in your calculation.

Mass balance calculations for estimating emissions to air of NPI-listed substances can be represented conceptually by Equation 8.

Equation 8

$$E_{kpy,i} = \text{Amount in}_i - \text{Amount out}_i$$

where:

$E_{kpy,i}$ = emissions of pollutant i, kg/yr
Amount in$_i$ = amount of pollutant i entering the process, kg/yr
Amount out$_i$ = amount of pollutant i leaving the process as a waste
stream, article or product, kg/yr

The term "Amount out$_i$" may actually involve several different fates for an individual pollutant. This could include the amount recovered or recycled, the amount leaving the process in the manufactured product, the amount leaving the process in wastewater, the amount emitted to the atmosphere, or the amount of material transferred off-site as hazardous waste or to landfill. A thorough knowledge of the different fates for the pollutant of interest is necessary for an accurate emission estimate to be made using the mass balance approach.

The amount of a particular substance entering or leaving a facility is often mixed within a solution as a formulation component or as a trace element within the raw material. To determine the total weight of the substance entering or leaving the process, the concentration of the substance within the material is required. Using this concentration data, Equation 9 can be applied as a practical extension of Equation 8.

Equation 9

$$E_{kpy,i} = [(Q_{in} * C_{in}) - (Q_{pr} * C_{pr}) - (Q_{rec} * C_{rec}) - (Q_{waste} * C_{waste})] / 10^6$$

where:

$E_{kpy,i}$ = emissions of pollutant i, kg/yr
$Q_{in}, Q_{pr}, Q_{rec}, Q_{waste}$ = quantity of raw material, product, recycled material or waste
respectively, that is processed (generally expressed in kg for
solids, L for liquids)
$C_{in}, C_{pr}, C_{rec}, C_{waste}$ = concentration of substance i in the raw material, product,
recycled material or waste respectively, that is processed annually
(usually mg/kg for solids, mg/L for liquids)
10^6 = conversion from milligrams to kilograms.

Wastewater treatment may precipitate the reportable chemical in a sludge. Facilities are often required to obtain data on the concentration of metals or other substances in sludges as part of their licensing requirement and this data can be used to calculate the emissions as kilograms of sludge multiplied by the concentrations of the substance in the sludge. Although listed substances in sludges transferred off-site do not require reporting, determining this loss can assist with determining other process losses or may require reporting if the sludge is disposed of on-site.

For many chemicals used and emitted during chemical processes, some degradation in treatment may occur so that the entire chemical is not transferred to the sludge. Facilities can estimate the amount of reportable compounds in the sludge by using measured data, or by subtracting the amount biodegraded from the total amount removed in treatment. The amount of removal can be determined from operating data, and the extent of biodegradation might be obtained from published studies. If the biodegradability of the chemical cannot be measured or is not known, reporting facilities should assume that all removal is due to absorption to sludge.

A.3   Engineering Calculations

An engineering calculation is an estimation method based on physical/chemical properties (eg. vapour pressure) of the substance and mathematical relationships (eg. ideal gas law).

A.3.1 Fuel Analysis

Fuel analysis is an example of an engineering calculation and can be used to predict SO_2, metals, and other emissions based on application of conservation laws, if fuel rate is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements such as sulfur that may be converted into other compounds during the combustion process.

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

Equation 10

$$E_{kpy,i} = Q_f * C_i/100 * (MW_p /EW_f) * OpHrs$$

where:

$E_{kpy,i}$ = annual emissions of pollutant i, kg/yr
Q_f = fuel use, kg/hr
OpHrs = operating hours, hr/yr
MW_p = molecular weight of pollutant emitted, kg/kg-mole
EW_f = elemental weight of pollutant in fuel, kg/kg-mole
C_i = concentration of pollutant i in fuel, weight percent, %

For instance, SO_2 emissions from fuel oil combustion can be calculated based on the concentration of sulfur in the fuel oil. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO_2 (MW = 64) are emitted. The application of this EET is shown in Example 6.

> **Example 6 - Using Fuel Analysis Data**
>
> This example shows how SO_2 emissions can be calculated from fuel combustion based on fuel analysis results, and the known fuel flow of the engine. $E_{kpy,SO2}$ may be calculated using Equation 10 and given the following:
>
> | | | |
> |---|---|---|
> | Fuel flow (Q_f) | = | 20 900 kg/hr |
> | Weight percent sulfur in fuel | = | 1.17 % |
> | Operating hours | = | 1500 hr/yr |
>
> $$E_{kpy,SO2} = Q_f * C_i/100 * (MW_p / EW_f) * OpHrs$$
> $$= (20\ 900) * (1.17/100) * (64 / 32) * 1500$$
> $$= 733\ 590\ kg/yr$$

A.4 Emission Factors

In the absence of other information, default emission factors can be used to provide an estimate of emissions. Emission factors are generally derived through the testing of a general source population (eg. boilers using a particular fuel type). This information is used to relate the quantity of material emitted to some general measure of the scale of activity (eg. for boilers, emission factors are generally based on the quantity of fuel consumed or the heat output of the boiler).

Emission factors require 'activity data', that is combined with the factor to generate the emission estimates. The generic formula is:

Equation 11

$$\text{Emission Factor}\left(\frac{\text{mass}}{\text{unit of activity}}\right) * \text{Activity Data}\left(\frac{\text{unit of activity}}{\text{time}}\right) = \text{Emission Rate}\left(\frac{\text{mass}}{\text{time}}\right)$$

For example, if the emission factor has units of '*kg pollutant/m³ of fuel combusted*', then the activity data required would be in terms of '*m³ fuel burned/hr*', thereby generating an emission estimate of '*kg pollutant/hr*'.

An emission factor is a tool used to estimate emissions to the environment. In this Manual, it relates the quantity of substances emitted from a source, to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted, divided by the unit weight, volume, distance, or duration of the activity emitting the substance (eg. kilograms of sulfur dioxide emitted per tonne of fuel burned).

Emission factors are used to estimate a facility's emissions by the general equation:

Equation 12

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

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 of pollutant i, %.

Emission factors developed from measurements for a specific process may sometimes be used to estimate emissions at other sites. Should a company have several processes of similar operation and size, and emissions are measured from one process source, an emission factor can be developed and applied to similar sources. It is necessary to have the site specific emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

Appendix B - Emission Estimation Techniques: Acceptable Reliability and Uncertainty

This section is intended to give a general overview of some of the inaccuracies associated with each of the techniques. Although the National Pollutant Inventory does not favour one emission estimation technique over another, this section does attempt to evaluate the available emission estimation techniques with regards to accuracy.

Several techniques are available for calculating emissions from gas supply facilities. The technique chosen is dependent on available data, and available resources, and the degree of accuracy sought by the facility in undertaking the estimate.

B.1 Direct Measurement

Use of stack and/or workplace health and safety sampling data is likely to be a relatively accurate method of estimating air emissions from gas supply facilities. However, collection and analysis of samples from facilities can be very expensive and especially complicated where a variety of NPI-listed substances are emitted, and where most of these emissions are fugitive in nature. Sampling data from a specific process may not be representative of the entire manufacturing operation, and may provide only one example of the facility's emissions.

To be representative, sampling data used for NPI reporting purposes needs to be collected over a period of time, and to cover all aspects of production.

In the case of CEMS, instrument calibration drift can be problematic and uncaptured data can create long-term incomplete data sets. However, it may be misleading to assert that a snapshot (stack sampling) can better predict long-term emission characteristics. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and the corresponding emissions data.

B.2 Mass Balance

Calculating emissions from gas supply facilities using mass balance appears to be a straightforward approach to emission estimation. However, it is likely that few Australian facilities consistently track material usage and waste generation with the overall accuracy needed for application of this method. Inaccuracies associated with individual material tracking, or other activities inherent in each material handling stage, can result in large deviations for total facility emissions. Because emissions from specific materials are typically below 2 percent of gross consumption, an error of only ± 5 percent in any one step of the operation can significantly skew emission estimations.

B.3   Engineering Calculations

Theoretical and complex equations, or models, can be used for estimating emissions from gas supply processes. Use of emission equations to estimate emissions from gas supply facilities is a more complex and time-consuming process than the use of emission factors. Emission equations require more detailed inputs than the use of emission factors but they do provide an emission estimate that is based on facility-specific conditions.

B.4   Emission Factors

Every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks.   They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited can be found in the reference section of this document. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or Category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A   -   Excellent
B   -   Above Average
C   -   Average
D   -   Below Average
E   -   Poor
U   -   Unrated

Appendix C - List of Variables and Symbols

Variable	Symbol	Units
Conversion from kilograms to tonnes	10^3	kg/tonne
Conversion from milligrams to kilograms	10^6	mg/kg
Density of air	ρ_a	kg/m^3
Density of material	ρ_m	kg/L
Dry density of stack gas sample	ρ_{STP}	kg/m^3 at STP
Activity rate	A	units/hr, eg. t/hr
Surface area	area	m^2
Overall control efficiency	CE_i	% reduction in emissions of pollutant i
Filter Catch	C_f	grams
Concentration of pollutant i	C_i	kg/L
Concentration of pollutant i in material	C_i	kg/L
Concentration of substance i in the raw material, product, recycled material or waste respectively, that is processed annually	C_{in}, C_{pr}, C_{rec}, C_{waste}	(usually mg/kg for solids, mg/L for liquids)
Concentration of PM_{10}	C_{PM10}	$grams/m^3$
Uncontrolled emission factor for pollutant i	EF_i	kg of pollutant/tonne
Total emissions of pollutant i per hour	E_i	kg/hr
Emissions per tonne	$E_{kpt,i}$	kilograms of pollutant i per tonne of fuel consumed
Annual emissions of pollutant i	$E_{kpy,i}$	kg/yr
Elemental weight of pollutant in fuel	EW_f	kg/kg-mole
Molecular Weight of pollutant i	MW_i	kg/kg-mole
Operating hours	OpHrs	hr/yr
Pollutant concentration	ppm_{vd}	volume of pollutant gas/10^6 volume of dry air
Saturation vapour pressure of pollutant i	$P_{sat,i}$	kilopascals (kPa)
Total pressure	P_t	kPa
Vapour pressure of pollutant i	$P_{vap,i}$	kPa
Volumetric flow rate,	Q	m^3/s
Volumetric flow rate of stack gas	Q_a	actual cubic metres per second (m^3/s)
Volumetric flow rate of stack gas	Q_d	dry cubic metres per second (m^3/s)
Fuel used	Q_f	t/hr
Material entering the process	Q_{in} or Amount in$_i$	kg/hr
Material leaving the process	Q_{out} or Amount out$_i$	kg/hr
Ideal gas constant	R	$kPa.m^3$ /(kgmol).K
Standard Temperature & Pressure	STP	0^oC (273 K) and 1 atmosphere 101.3 kPa
Temperature	T	^{o}Celsius (^oC) or Kelvin (K)
Total suspended particulates or Total particulate matter (total PM)	TSP or PM	mg/m^3
Metered volume at STP	$V_{m,STP}$	m^3
Total VOC emissions	E_{VOC}	kg/L
Moisture collected	g_{moist}	grams
Moisture content	$moist_R$	%
Percentage weight of pollutant i	$Wt\%_i$	%