National Pollutant Inventory

Emission Estimation Technique Manual

for

Intensive Livestock - Pig Farming

First published in December 1999

EMISSION ESTIMATION TECHNIQUES
FOR
PIG FARMING

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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 Intensive Livestock (Pig Farming). These operations consist of a number of activities including feedstock storage, feeding systems, animal housing, disposal of biological matter, waste removal/storage and waste treatment. Some facilities also use animal biogas to produce power on site. In addition, the on-site irrigation of effluent is covered by this Manual.

> EET MANUAL: Pig Farming
>
> HANDBOOK: Intensive Livestock (Pig Farming)
>
> ANZSIC CODE: 0151

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 Pig Research and Development Cooperation 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 intensive livestock (pig farming) industry.
- **Section 3.1** discusses the term 'transfer' as it applies to the intensive livestock (pig farming) industry.
- **Section 3.2** summarises the NPI-listed substances that are triggered, or likely to be triggered, for the intensive livestock (pig farming) industry. Category 1, 2 and 3 substances are discussed in **Sections 3.2.1, 3.2.2** and **3.2.3** respectively. **Sections 3.3, 3.4** and **3.5** 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 intensive livestock (pig farming) industry.

- **Appendix B** provides a discussion of the reliability and uncertainty involved 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 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 Intensive Livestock (Pig Farming) 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 exceed 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 3.2.1** of this Manual for guidance on which Category 1 substances are likely to require reporting for the intensive livestock (pig farming) industry. 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.

Category 2a and 2b Substances:

Determine the amount and rate of fuel (or waste) burnt each year and assess whether the threshold limits are exceeded. See **Section 3.2.2** of this Manual for a discussion of which Category 2 substances are likely to be triggered for the intensive livestock (pig farming) 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 intensive livestock (pig farming) 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 covers the Intensive Livestock (Pig Farming) industry as defined under ANZSIC Code 0151 - Pig Farming. These operations consists of a number of activities including feedstock storage, feeding systems, animal housing, disposal of biological matter, waste removal/storage, waste treatment and on-site irrigation. Some facilities also use animal biogas to produce power on site.
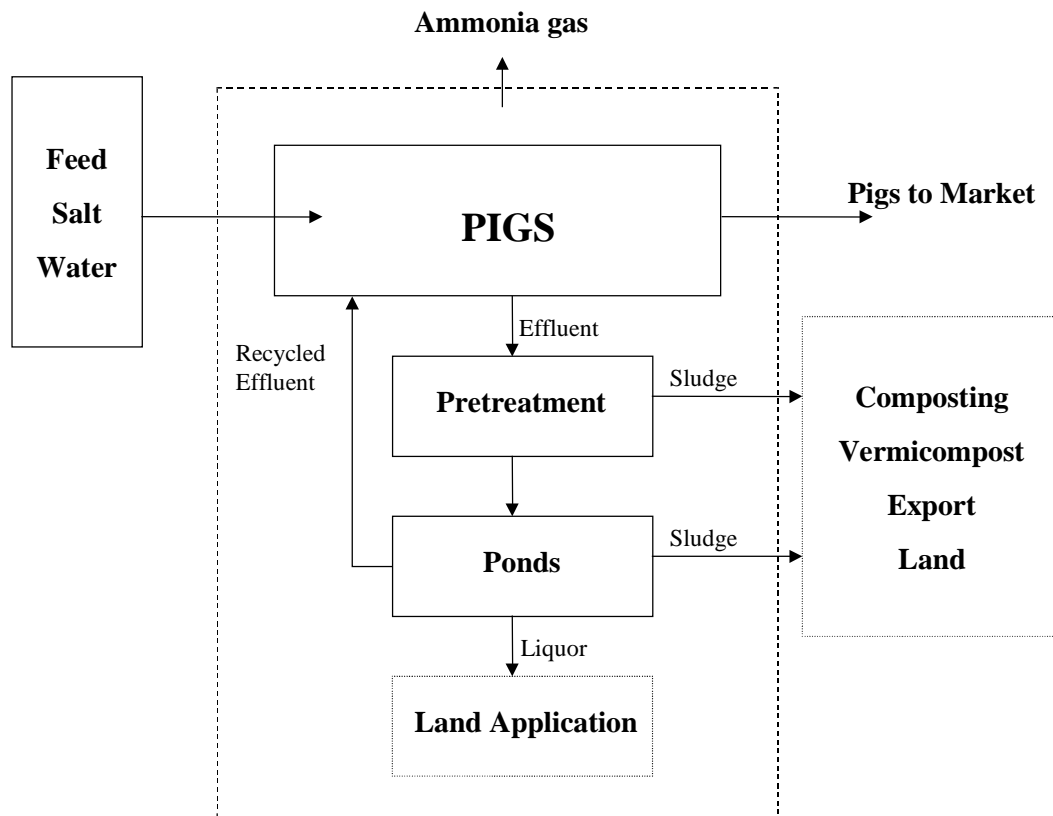
Figure 1 - Intensive Livestock (Pig Farming): Process Inputs and Emissions
(Source: Kruger et al, 1995)

3.0   Reportable Emission Sources

3.1   Transfers

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

- Discharges of substances to sewer;
- 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.'

In the specific context of intensive livestock (pig farming), the NPI Implementation Working Group, at its meeting of 13 February 1999, agreed that the on-site irrigation of effluent or wastewater will be considered as an emission. Also, that any NPI-listed substances, for which reporting thresholds are triggered, associated with these emissions must be quantified and reported. Effluent sent off site for application on another facility is defined as a transfer and the emissions from this are required to be reported by the receiving facility.

3.2   Reporting Thresholds

The intensive livestock pig farming industry potentially has NPI reporting requirements associated with:
- Ammonia produced from animals (see Section 3.2.1 for guidance on how to determine whether or not reporting on this is required for your facility);
- Emissions to air associated with the combustion of biogas, , natural gas, diesel or LPG (see Section 3.2.2);
- Releases to surface waters of nitrogen or phosphorous (see Section 3.2.3).

3.2.1   Category 1

The substances listed under Category 1 and 1a of the NPI have extremely limited use as inputs into the pig farming industry. There are only minor quantities of chemicals used for cleaning and veterinary purposes etc and it is extremely unlikely these substances would amount to 10 tonnes per year triggering limit.

However, it is likely that some facilities will trigger the 10 tonnes per year limit for ammonia (as a consequence of the ammonia and the organic nitrogen that can be mineralised to ammonia in pig manure). Use the default data on total nitrogen production given in Table 1 to determine whether or not the 10 tonnes per year threshold of ammonia

would be exceeded at a particular facility. Assume a conversion rate from nitrogen to ammonia of 0.7 kg NH_3 volatised/kg total N (see example 1 for a discussion of the derivation of this conversion rate). Example 1 illustrates the application of this data.

Table 2, which is based on the data provided in Table 1, provides an indication of the minimum piggery sizes which would lead to NPI reporting being triggered for the intensive livestock (pig farming) industry.

Table 1 - Total Nitrogen in Fresh Manure from Piggeries

Piggery or Production Unit	Standard Pig Units (SPU)	Total Nitrogen (kg/day)
100 Sow - Farrow to Finish (24 wks/100kg)	990	25.5
100 Sow - Farrow to Pork (16wks/55kg)	542	13.4
100 Sow - Farrow to Weaner (10wks/25kg)	328	8.1
100 Sow - Farrow to Sucker (4wks/9kg)	214	5.6
500 pig grower unit (progeny of 100 Sow Farrow to Weaner) (25-100kg)	661	17.4

Source: Qld DPI, 1999

Note: It is relevant to note that these data compare favourably with the data for total nitrogen emissions provided in Kruger *et al*, 1995 (although the data quoted by Kruger *at al* was derived from US data).

Example 1 - Category 1 Threshold Calculations

A pig farmer has a 300 sow, farrow to finish unit. Is the Category 1 threshold for ammonia exceeded for the facility? (Note: In the absence of site-specific data, assume 0.7 kg of ammonia is volatised per kg of total nitrogen input[a]).

Determine the amount of ammonia produced per day:
Ammonia per day   = 3 * 25.5 kg total N/day * 0.7 kg NH_3 volatised/kg total N
                            = 53.55 kg/day

Determine annual production of ammonia:
Ammonia per year = 365 * amount of ammonia produced per day
                            = 365 days/year * 53.55 kg/day
                            = 19 545 kg/year
                            = 19.54 tonnes of ammonia per year

This exceeds the Category 1 threshold and, therefore, reporting of emissions of ammonia to air, water and land would be required for the facility.

[a] This default value was calculated using the data from Table 2, and assuming that the piggery consisted of Pig Shed, Primary Anaerobic Pond, Secondary Facultative Pond, Final Irrigation Pond and some irrigation on-site occurred.

Table 2 - Minimum Piggery Sizes to Trigger Reporting for Ammonia[a]

Piggery or Production unit	Minimum Number of Total Pigs (and corresponding number of sows) to Trigger 10 Tonnes per Annum Threshold for Ammonia[b]
Farrow to Finish (24wks/100kg)	1516 pigs (153 sows)
Farrow to Pork (16wks/55kg)	2068 pigs (292 sows)
Farrow to Weaner (10wks/25kg)	2372 pigs (483 sows)
Farrow to Sucker (4wks/9kg)	1838 pigs (699 sows)
Grow out unit (20-95kg)	1113 pigs (no sows)

[a] Note: Based on data contained in Table 1 of this Manual, assuming 0.7 kg of ammonia is volatilised per kg of total nitrogen produced.

[b] Note: A pig farm would trigger the ammonia threshold if;
 it farms more than the actual number of pigs to trigger the threshold as outlined in Table 2
 or it farms more than 1500 Standard Pig Units.

[c] Note: A grow out unit consists of only growers and finishers (no sows). The data in Table 2 assumes a continuous (365day/year) production. If the grow out unit is vacant for part of the year, then divide this number by the fraction of the year that the unit is occupied. For example, if a unit is vacant for ¼ of the year, then the minimum number of pigs to trigger is 1113 pigs/ 0.75 year = 1484 pigs/year.

[d] Note: This table has been based on the following values of SPU per type of pig;
 Gilts = 1.8 SPU; Gestating Sows = 1.6 SPU; Lactating Sows = 2.5 SPU; Boars = 1.6 SPU.
 Suckers = 0.1 SPU; Weaners = 0.5 SPU; Growers = 1.0 SPU; Finishers = 1.6 SPU

3.2.2 Category 2

The Category 2 threshold is based on energy consumption or 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.

For the intensive livestock (pig farming) industry, the Category 2 threshold may be triggered by either:

- Biogas combustion; and/or
- Combustion of other fuels such as LPG, natural gas or diesel.

Each of these sources is discussed below and guidance provided on how to determine whether or not reporting is required for Category 2 substances.

Biogas

For facilities with biogas combustion systems, a simple calculation (Example 2 below) can be performed to determine whether or not reporting is required. The example calculation shown is for the effluent treatment system at Berrybank Farm. At the time of preparing this Manual (August 1999), Berrybank was the only farm in Australia with on-site power generation from biogas combustion. However, it is understood that a number of other farms are currently investigating the potential for biogas combustion.

Example 2 - Generation of Power via Biogas Combustion - (Note: Data taken from Kruger *et al*, 1995)

Amount of biogas produced per day = 1700 m^3/day
Therefore:
Amount of biogas produced per year = 1700 m^3/day * 365 days/year
                                                        = 620 500 m^3 biogas/year
Ideal gas law: PV = nRT
                                                          n = PV/RT
where: n = number of moles
                                                          P = pressure (assumed atmospheric = 101 325 Nm^{-2})
                                                          V = volume of gas (620 500 m^3 of biogas)
                                                          R = constant (8.314 Nm mol^{-1} K^{-1})
                                                          T = temperature (assumed ambient = 298 K)

So, number of moles of biogas produced per year
                                     = (101 325 * 620 500)/(8.314 * 298)
                                     = 25 376 520 moles/year
Molecular weight for biogas = 25.8 g (65% CH$_4$ & 35% CO$_2$)

Therefore,
Mass of biogas burnt per year = 25 376 520 moles * 28.5 g * 1 * 10^{-6} tonne/g
                                     = 655 tonnes/year
                      (ie. reporting triggered for Category 2a substances)

Therefore, a piggery that burns more than 1040 m^3 of biogas/day will trigger the NPI reporting threshold for Category 2a substances.

Other Combustion

Table 3 details the amount of fuel usage required to trigger the Category 2 reporting thresholds for the fuels likely to be used in piggery operations.

It is important to note that Category 2 threshold calculations should be performed for total fuel usage. If a number of different fuels are used at one facility, the sum of each individual fuel use needs to be calculated to determine whether or not the Category 2 threshold is triggered.

If a facility triggers the Category 2b threshold, Category 2a and 2b pollutants need to be reported.

Table 3 - Approximate Fuel Usage Required to Trigger Category 2 Thresholds

Fuel Type	Category 2a	Category 2b
Natural Gas[a]	$2.06 * 10^7$ MJ per reporting year, or at least $5.12 * 10^4$ MJ in any one hour in the reporting year	$1.03 * 10^8$ MJ per reporting year
Liquefied Petroleum Gas (LPG)[b]	$7.87 * 10^5$ L per reporting year, or at least $1.97 * 10^3$ L in any one hour in the reporting year	$3.94 * 10^6$ L per reporting year
Biogas[c]	$3.67 * 10^5$ m^3 per reporting year, or at least $9.17 * 10^2$ m^3 in any one hour in the reporting year	$1.83 * 10^6$ m^3 per reporting year
Diesel[d]	$4.44 * 10^5$ L per reporting year, or at least $1.11 * 10^3$ L in any one hour in the reporting year	$2.22 * 10^6$ L 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)

[b] Assuming ideal gas with a density of 508 kg/m^3 at 15°C under pressure from the *Natural Gas Technical Data Handbook* (AGL Gas Company (NSW) Limited, 1995)

[c] Assuming 65% methane and 35% carbon dioxide ideal gas by volume with a density of 1.09 kg/m^3 at 15°C and 101.325 kPa.

[d] Assuming a density of 900 kg/m^3 at 15°C for fuel oil for commercial use (Perry, et al., 1997)

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. Category 2 substances are listed in Table 4

Table 4 - 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 & 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

Note: For natural gas and LPG combustion, emissions of fluoride compounds are not required to be reported (NPI Implementation Working Group decision, February 1999).

3.2.3 Category 3

From discussions with the industry, piggery are not generally permitted to discharge effluent to surface waters. Effluent is generally directed to holding ponds and wastewater treatment processes. The liquor from the ponds is generally used for irrigation purposes.

Given that piggeries are not generally permitted to routinely release effluent or treated effluent to surface waters, it is likely that the only event that would cause such a release would be an unplanned situation such as extreme rainfall events or leaks/breaks in a settlement pond wall. In such events, it is extremely unlikely that the Category 3 reporting thresholds would be exceeded. However, there may be a need to estimate the total phosphorous and total nitrogen released to make a definitive assessment.

Table 5 provides generic guidance on the characteristics of effluent at different stages of the treatment process. It should be noted that the data contained in this table should be used with caution. It is provided for guidance purposes only and is not a substitute for individual (ie site-specific) piggery data.

Table 5 - Average Measured Effluent Characteristics at Different Stages of the Treatment Process

Parameter	Prior to Screen	Screened Liquids	Pond 1 liquor (screened)	Sludge	Final Pond
Phosphorus (mg/L)	850		109	1696	44
Total Nitrogen[a] (mg/L)	2175	1391	854	2617	384
Ammonia (mg/L)	1800		398	1156	249

Source: Kruger *et al*, 1995

[a] Kruger *et al* actually refer to Total Kjedahl Nitrogen (TKN), rather than Total Nitrogen. TKN is the standard chemical analysis for the sum of organic nitrogen and ammonium nitrogen but does not measure nitrates or nitrites. For pig manure, organic nitrogen comprises some 90-95% of the total nitrogen and, in this situation, TKN can be taken as a reasonable approximation for Total Nitrogen.

Example 3 illustrates the application of these data to estimate the amount of nitrogen and phosphorus released in the event of a spill.

Example 3 - Category 3 Threshold Calculations

A spill of 100 000 litres has occurred from an effluent treatment pond. The only prior treatment of the effluent was screening. Has a Category 3 NPI reporting threshold been exceeded?

Refer to Table 5 to determine the concentration of total nitrogen and total phosphorus in the effluent. (NB: You should only use the data in Table 5 if site-specific data is unavailable.)

Concentration of Nitrogen = 854 mg/L
Concentration of Phosphorus = 109 mg/L

Total amount released = concentration * amount released

Total nitrogen released = 854 mg/L * 100 000 L
= $8.54 * 10^7$ mg
= 85.4 kg released

Total phosphorus released = 109 mg/L * 100 000 L
= $1.09 * 10^7$ mg
= 10.9 kg released

These releases are significantly less than Category 3 thresholds of 15 tonnes per annum for total nitrogen and 3 tonnes per annum for total phosphorus. Therefore, in this situation, no reporting of Category 3 substances would be required.

3.3 Emissions to Air

Section 3.3.1 provides guidance on the characterisation of emissions of ammonia to air from piggery operations. Section 3.3.2 provides guidance on characterising emissions to air of Category 2 substances.

3.3.1 Ammonia

Ammonia is released to air throughout the operation, from the pig sheds through to the final effluent treatment and disposal processes (ie. land application of effluent). Accurately estimating the quantities of ammonia emitted can be difficult and/or expensive. Although there are no standard methods for estimating the quantity of ammonia released to the atmosphere from a pig farm, the Queensland Department of Primary Industries has produced the information contained in Table 6 to estimate ammonia emissions. It should be noted that the 'Percentage of Total Nitrogen Volatilised' is expressed as a percentage of the Total Nitrogen input to the stage. In the absence of piggery specific data, the information that is provided in Table 6 could be used (in conjunction with Table 2) as default values to calculate the ammonia losses from pig farming.

Table 6 - Percentage of Total Nitrogen Volatised (as NH$_3$) from Various Stages of an Intensive Pig Farming Facility

Component	Percentage of Total Nitrogen volatised (as percentage of Total Nitrogen input to each Stage)
Pig shed	10[a]
Screen removal	8[b]
Primary Anaerobic Pond	26[a]
Secondary Facultative Pond	18[a]
Final Irrigation Pond	26[a]
Soil (post irrigation)	25[b]
Irrigation	25[b]

Source: Qld DPI, 1999
[a] Estimate produced by modelling.
[b] Estimate derived from international data reported in scientific literature.

To calculate emissions of ammonia for the purposes of NPI reporting, the following steps should be followed:

Step 1

Determine total ammonia production (refer to Section 3.2.1).

Step 2

Identify the activities conducted at the facility and the corresponding percentage of ammonia released (see Table 6 above).

The key issue is that it is only on-site releases of ammonia, which are to be reported. This includes ammonia emissions from on-site irrigation. However, emissions of ammonia from off-site irrigation are not required to be estimated.

Step 3

Multiply the total ammonia input to the activity by the percentage released (Step 3) for each activity component. The total amount of ammonia released is the sum of the releases to air from each individual activity. It is important to note that, for each stage subsequent to the first stage, the ammonia input to the stage is the difference between the ammonia input to the previous stage and the ammonia released in the previous stage.

Example 4 demonstrates the calculation of ammonia releases. The example involves the calculation of ammonia from each individual source at a specific facility, using the step by step approach outlined above.

Example 4 - Estimation of Ammonia Releases

The pig farmer (ie. a 300-sow farrow to finish unit) is required to report ammonia releases to the NPI. Waste treatment at the facility consists of a primary anaerobic pond, a secondary facultative pond and a final irrigation pond from which 1.5 ML/yr of irrigation water is applied to his land. Some of this water is also supplied to a neighbouring farm for irrigation purposes. Solids screening occurs between the pig shed and the primary anaerobic pond. The anaerobic pond, facultative pond and the irrigation pond each have a capacity of 19 000 m^3, 4500 m^3 and 3500 m^3 respectively. The irrigation pond has a throughput of 8000 L/day.

Estimate the amount of ammonia released to the atmosphere from the facility.

Pig Shed
From Table 1, the amount of total nitrogen produced each day from a 100-sow pig shed is 25.5 kg/day. So for a 300-sow unit;

Amount of nitrogen produced	= 3 * 25.5 kg/day.
	= 76.5 kg/day

From Table 6, 10% of the nitrogen in the pig shed is lost to volatilisation. So the amount of nitrogen volatised = 10% of 76.5 kg/day.
= 7.65 kg/day.

Amount of ammonia volatilised	= nitrogen * $MW_{ammonia}$/$EW_{nitrogen}$
	= 65 kg/day * 17/14
	= 9.29 kg/day

The amount of ammonia released per year (from the pig shed)
= 365 days/year * 9.29 kg/day.
= 3390.85 kg/year of ammonia.

Ammonia Screen losses

Amount of nitrogen remaining in effluent
= 76.5 kg/day - 7.65 kg/day volatised.
= 68.85 kg/day.

From Table 6, 8% of the nitrogen from screen removal is lost to volatilisation. So the amount of nitrogen volatised = 8% of 68.85 kg/day.
= 5.51 kg/day.

Amount of ammonia	= nitrogen * $MW_{ammonia}$/$EW_{nitrogen}$
	= 5.51 kg/day * 17/14
	= 6.69 kg/day

Example 4 - Estimation of Ammonia Releases cont'

The amount of ammonia released per year (from screen removal).
$$= 365 \text{ days/year} * 6.69 \text{ kg/day.}$$
$$= 2442.11 \text{ kg/year of ammonia.}$$

Primary Anaerobic Pond
Amount of nitrogen entering pond
$$= 68.85 \text{ kg/day} - 5.51 \text{ kg/day volatised.}$$
$$= 63.34 \text{ kg/day.}$$

From Table 6, 26% of the nitrogen in the anaerobic pond is lost to volatilisation. So the amount of nitrogen volatised $\quad = 26\% \text{ of } 63.34 \text{ kg/day.}$
$$= 16.47 \text{ kg/day.}$$

Amount of ammonia $\quad\quad\quad = \text{nitrogen} * MW_{ammonia}/EW_{nitrogen}$
$$= 16.47 \text{ kg/day} * 17/14$$
$$= 20.0 \text{ kg/day}$$

The amount of ammonia released per year (from the anaerobic pond).
$$= 365 \text{ days/year} * 20.0 \text{ kg/day.}$$
$$= 7300 \text{ kg/year of ammonia.}$$

Note: Alternately, if site-specific data for the average concentration of total nitrogen in each pond were available, the following calculation would be viable.

Effluent concentration * % volatilisation * Annual throughput of the pond = amount of ammonia released annually.

Secondary Facultative Pond
Amount of nitrogen entering pond = 63.34 kg/day - 16.47 kg/day volatised.
$$= 46.87 \text{ kg/day.}$$

From Table 6, 18% of the nitrogen in the facultative pond is lost to volatilisation. So the amount of nitrogen volatised $\quad = 18\% \text{ of } 46.87 \text{ kg/day.}$
$$= 8.44 \text{ kg/day.}$$

Amount of ammonia $\quad\quad\quad = \text{nitrogen} * MW_{ammonia}/EW_{nitrogen}$
$$= 8.44 \text{ kg/day} * 17/14$$
$$= 10.24 \text{ kg/day}$$

The amount of ammonia released per year (from the facultative pond).
$$= 365 \text{ days/year} * 10.24 \text{ kg/day.}$$
$$= 3739.22 \text{ kg/year of ammonia.}$$

Example 4 - Estimation of Ammonia Releases cont'

Note: Alternately, if site-specific data for the average concentration of total nitrogen in each pond were available, the following calculation would be viable.

Effluent concentration * % volatilisation * Annual throughput of the pond = amount of ammonia released annually.

Irrigation Pond
If site-specific data is not known, the same mass balance technique that has been used for the previous ponds cannot be used unless the amount of nitrogen in the sludge can be determined. Therefore, as a default the information from Table 5 can be used as an estimate of the nitrogen concentration in the final irrigation pond.

From Table 5, concentration of nitrogen in the final pond = 384 mg/L

The throughput of effluent is 8000 L/day, and from Table 6, 26% of the nitrogen in the irrigation pond is lost to volatilisation. So the amount of nitrogen volatised
$$= 0.26 * 384 \text{ mg/L} * 8000 \text{ L/day} * 1/1000\,000 \text{ kg/mg}$$
$$= 0.798 \text{ kg/day}.$$

Amount of ammonia
$$= \text{nitrogen} * MW_{ammonia}/EW_{nitrogen}$$
$$= 0.798 \text{ kg/day} * 17/14$$
$$= 0.97 \text{ kg/day}$$

The amount of ammonia released per year (from the irrigation pond).
$$= 365 \text{ days/year} * 0.97 \text{ kg/day}.$$
$$= 354.05 \text{ kg/year of ammonia}.$$

Irrigation of Effluent

Under the definition by the Industry Working Group for the NPI, irrigation of the effluent to a neighbour's property is considered as a transfer. However the irrigation of effluent on-site must be included in the calculations for ammonia production.

From Table 6, 25% of the nitrogen in the irrigation water is lost to volatilisation. So the amount of nitrogen volatised;
$$= 0.25 * 384 \text{ mg/L} * 1\,500\,000 \text{ L/yr} * 1 \text{ kg}/1\,000\,000 \text{ mg}$$
$$= 144 \text{ kg/year of nitrogen}$$

Amount of ammonia
$$= \text{nitrogen} * MW_{ammonia}/EW_{nitrogen}$$
$$= 144 \text{ kg/year} * 17/14$$
$$= 175 \text{ kg/year}$$

Example 4 - Estimation of Ammonia Releases cont'

Soil Losses after Irrigation

From Table 6, 25% of the nitrogen remaining in the effluent that reaches the soil is volatilised.

Amount of nitrogen in soil = 0.75 * concentration of nitrogen * amount irrigated
= 0.75 * 384 mg/L * 1 500 000 L/year * 1kg/
1 000 000 mg
= 432 kg/year

Therefore, total nitrogen volatilised = % volatilised * amount in soil
= 0.25 * 432 kg/year
= 108 kg/year

Ammonia volatilised = nitrogen * $MW_{ammonia}/EW_{nitrogen}$
= 108 kg/year * 17/14
= 131 kg/year

Total amount of Ammonia released to Air

Total NH_3 released = Pig Shed + Screens +Anaerobic Pond + Facultative Pond + Irrigation
Pond + Effluent Irrigation + Ammonia from Soil after Irrigation
= 3390.85 kg/yr + 2442.11 kg/yr + 7300 kg/yr + 3739.22 kg/yr +
354.05 kg/yr + 175 kg/yr + 131 kg/yr
= 17 531 kg/yr
= 17.531 tonnes/yr

Note: The emissions from irrigation (to neighbour) and from the sludge (sold off-site) are classed as transfers and hence are not reportable to the NPI. Emissions from the spreading of manure sludge from ponds and screens (on-site) are considered to contain mainly inorganic nitrogen and organic nitrogen that is bound and hence minimal emissions of ammonia will be released. There is currently no published data available to estimate these emissions.

3.3.2 Category 2 Substances

No emission factors are presently available for the combustion of biogas in boilers. In the absence of other information, a starting point for estimating emissions from biogas combustion is to assume that the combustion of biogas produces similar emissions to the combustion of natural gas (as presented in the *Emission Estimation Technique Manual for Combustion in Boilers).*

For a discussion on how to estimate emissions from combustion of fuels other than biogas refer also to the *Emission Estimation Technique Manual for Combustion in Boilers.* For combustion engines (eg diesel), refer to the *Emission Estimation Technique Manual for Combustion Engines*.

If the Category 2 threshold is exceeded, all releases of PM_{10} need to be reported. There are currently no emission factors available for estimating emissions of PM_{10} from piggeries. The *Emission Estimation Technique Manual for Fugitive Emissions* does, however, provide some general guidance on the characterisation of emissions from buildings.

3.4   Emissions to Water

As Australian piggeries are, generally, prohibited to discharge effluent to surface waters it would only be in the event of an accidental or unplanned release or of a significant run-off from irrigation of sludge or effluent that reporting of total nitrogen and total phosphorus may be required.

However, as discussed in Section 3.2.3, even if such releases do occur, it is extremely unlikely that any such reporting would be required. However, if there is the potential for emissions of nitrogen and phosphorus to surface waters to exceed the Category 3 Reporting Thresholds, the calculation methodology outlined in Section 3.2.3 of this Manual should be used to assess whether or not reporting is required.

3.5   Emissions to Land

The on-site irrigation of slurry or effluent is classed as an emission under the NPI and reporting is required on this. For the purposes of NPI reporting, the only constituents of this that are required to be reported are:

- Ammonia. For the purposes of NPI reporting, it can be assumed that all ammonia is eventually volatilised (ie released to air) and, therefore, it can be assumed that there are no releases to land or to water. This will eliminate any potential for double counting of emissions. See Section 3.3 of this Manual for guidance on the calculation of these emissions to air.

- Run-off of nitrogen and phosphorous to surface water (see Section 3.4 above for a discussion of this).

4.0 Glossary of Technical Terms and Abbreviations

ANZSIC	Australian and New Zealand Standard Industrial Classification
Biogas	A gas (produced from decomposition of waste) comprising of approximately 65% methane and 35% carbon dioxide that can be burnt as fuel
CEMS	Continuous Emission Monitoring System
EEA	European Environment Agency
EET	Emission Estimation Technique
EFR	Emission Factor Rating
EW	Elemental Weight
Farrow	A litter of pigs
Finisher	A pig aged between 17-24 weeks
Gilt	A mature female pig that has not yet reproduced
Grower	A pig aged between 10-17 weeks
MW	Molecular Weight
NEPM	National Environment Protection Measure
NPI	National Pollutant Inventory
PM_{10}	Particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less (ie. $\leq 10 \mu m$)
SPU	Standard Pig Unit. The SPU is based on the amount of volatile solids that a 50kg grower pig producers.
Sucker	A pig less than 7 weeks of age
TKN	Total Kjeldahl Nitrogen - Organic Nitrogen and Ammonia Nitrogen
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
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
Weaner	A pig aged between 7-10 weeks

5.0 References

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

> *Emission Estimation Technique Manual for Combustion in Boilers;*
> *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.

The **usage**[a] 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.

[a]Usage is defined as meaning the handling, manufacture, import, processing, coincidental production or other uses of the substances.

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 6. 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 5.

Equation 1

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

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 = 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 7 - 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 5 - Using Stack Sampling Data

PM emissions calculated using Equation 1and Equation 2 (above) and the stack sampling data for Test 1 (presented in Table 6, 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 may it 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.

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

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 6 - Calculating Moisture Percentage

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

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

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

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 8 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 8 - 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 = 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

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

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

Example 7 - 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 8, and an exhaust gas temperature of 150°C (423 K).

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

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

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

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:

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

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.

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

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 in Equation 8.

Equation 8

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

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

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

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 8.

Example 8 - 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

$$E_{kpy,SO2} = Q_f * C_i/100 * (MW_p / EW_f) * OpHrs$$
$$= (20\,900) * (1.17/100) * (64 / 32) * 1500$$
$$= 733\,590 \text{ kg/yr}$$

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:

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

For example, if the emission factor has units of '*kg pollutant/m^3 of fuel burned*', then the activity data required would be in terms of '*m^3 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 11

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

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 intensive livestock (pig farming) 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 intensive livestock (pig farming) 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 intensive livestock (pig farming) 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 intensive livestock (pig farming) processes. Use of emission equations to estimate emissions from pig farming 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°C (273 K) and 1 atmosphere 101.3 kPa

Appendix C - List of Variables and Symbols cont'

Variable	Symbol	Units
Temperature	T	°Celsius (°C) 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	$Wt\%_i$	%