National Pollutant Inventory

Emission Estimation Technique Manual

for

Plasterboard and Plaster Manufacturing

5 February 2002
Version 1.1

Disclaimer

The manual was prepared in conjunction with Australian States and Territories according to the National Environment Protection (National Pollutant Inventory) Measure.

While reasonable efforts have been made to ensure the contents of this manual are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents and shall not be liable for any loss or damage that maybe occasioned directly or indirectly through the use of, or reliance on, the contents of this manual.

Erratum for Plasterboard and Plaster Manufacturing Emission Estimation Technique EET Manual (Version 1.1 – 5 February 2002).

Page	Outline of alteration
Table 4	Corrected polychlorinated dioxins and furans emission factor from 7.89E-11 to 8.01E-10.
Equation 10	Updated note below equation to reflect typical moisture levels of gypsum input material.

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PLASTERBOARD AND PLASTER MANUFACTURING
LIST OF EXAMPLES, FIGURES AND TABLES

1.0   Introduction

The purpose of all National Pollutant Inventory (NPI) 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 NPI. This manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in the processing of gypsum during plasterboard and plaster manufacturing.

The plasterboard and plaster manufacturing activities covered in this Manual apply to facilities primarily engaged in the manufacture of:

- plasterboard;
- industrial and building plasters (mouldings, cornices, sheets, and tiles);
- soil gypsum; and
- Portland cement additive.

EET MANUAL: Plasterboard & Plaster Manufacturing

HANDBOOK: Plaster Products Manufacturing

ANZSIC CODE: 263 and 2632

This Manual was initially drafted by the NPI Unit of the Queensland Department of Environment and Heritage and finalised by Environment Australia on behalf of the Commonwealth Government. It has been developed though a process of national consultation involving State and Territory environmental authorities and key stakeholders. Extensive work was completed by the major companies in the industry to develop industry specific emission factors to provide more comprehensive and effective reporting to the NPI.

The NPI Internet address is www.npi.gov.au. This site provides information for industry reporters in the NEWS section and a Frequently Asked Questions (FAQ) page that provides details of decisions relating to the program that may impact industry reporters.

2.0   Process Description

The following section presents a brief description of the Plasterboard and Plaster Manufacturing Industry and identifies likely sources of emissions.

2.1   General Processes

The plasterboard and plaster industry generates a broad range of products, primarily through physical modification of mined materials. Gypsum is calcium sulfate dihydrate ($CaSO_4.2H_2O$), a white or grey naturally occurring mineral. Raw gypsum ore is processed into a variety of products such as gypsum plasterboard, industrial and building plasters, soil conditioner, and Portland cement additive. To produce plasters or plasterboard, gypsum must be partially dehydrated or calcined to produce calcium sulfate hemihydrate ($CaSO_4.0.5H_2O$), commonly known as stucco.

This section describes the major industrial processes within the plasterboard and plaster products manufacturing industry, including the materials and equipment used and the processes employed. The section is designed to provide a general understanding of the industry and the inter-relationship between the industrial processes and the topics discussed in subsequent sections of the Manual (emissions of listed substances, estimating emissions, and control technologies).

This section specifically contains a description of commonly used production processes, associated raw materials, the by-products occurring, the NPI listed substances emitted, and the substances either recycled or transferred off-site. This discussion, coupled with the schematic drawing of the identified process, provides a concise description of where emissions may be produced in the process. This section also describes where NPI pollutants are emitted to – that is air, water, or land.

A flow diagram for a typical plaster production process producing both crude and finished plaster products is shown in Figure 1. In this process gypsum is crushed, dried, ground, and calcined. Not all of the operations shown in Figure 1 are performed at all Australian plasterboard and plaster production facilities. Some facilities produce only plasterboard, and many facilities do not produce soil conditioner. As each facility in Australia is likely to be different from any other facility, you are advised to develop a flow diagram for your particular operations that details the input of materials and listed substances and the waste sources and emissions resulting from the operation of each process.

Gypsum ore, from open pit mining operations, is crushed at the mine and then stockpiled. The stockpiled ore is further crushed and screened to about 50 millimetres in diameter ready for shipment to the manufacturing site. If the moisture content of the mined ore is greater than about 0.5 weight percent, the ore must be dried in a rotary dryer or a heater roller mill. Ore dried in a rotary dryer is conveyed to a roller mill, where it is ground to the extent that 90 percent of it is less than 150μm in diameter. The ground gypsum exits the mill in a gas stream and is collected in a product cyclone. Ore is sometimes dried in a roller mill by heating the gas stream, so that drying and grinding are accomplished simultaneously and no rotary dryer is needed. The finely ground gypsum ore is known as kettle feed, which may be used as a soil conditioner.

In most facilities, this material is fed to kettle calciners or flash calciners, where it is heated to remove three quarters of the chemically bound water to form stucco. Calcination occurs at approximately 120 to 150°C, and 1.0 tonne of gypsum calcines to about 0.85 tonne of stucco. In kettle calciners, the gypsum is heated by hot combustion gas passed through flues in the kettle, and the stucco product is discharged into a 'hot pit' located below the kettle. Kettle calciners may be operated in batch mode or continuously. In flash calciners, the gypsum is directly put in contact with hot gases, and the stucco product is collected at the bottom of the calciner.

At some gypsum facilities, drying, grinding, and calcining are performed in heated impact mills. In these mills, hot gas contacts gypsum as it is ground. The gas dries and calcines the ore and then

conveys the stucco to a product cyclone for collection. The use of heated impact mills eliminates the need for rotary dryers, calciners, and roller mills.

Potential emission sources in gypsum processing facilities are shown in Figure 1. While particulate matter (particles with an equivalent aerodynamic diameter of 10 micrometres or less i.e. ≤10μm), is the dominant emission from gypsum production facilities, several sources can also emit listed gaseous pollutants such as oxides of nitrogen, sulfur dioxide, and carbon monoxide from combustion processes. Emissions may also include listed metals and organic compounds arising from the fuel and raw materials used or which arise as products of incomplete combustion, possibly including small quantities of organic pollutants such as polycyclic aromatic hydrocarbons (PAHs)

Gypsum and stucco are usually transferred from one process to another by means of screw conveyors or bucket elevators. Storage bins or silos are normally located downstream of roller mills and calciners but may also be used elsewhere.

In the manufacture of plaster, the stucco is ground further in a tube or ball mill and then batch-mixed with retarders and stabilisers to produce plasters with specific setting rates. Once the plaster has been thoroughly mixed, the plaster is fed continuously from intermediate storage bins to a bagging operation.

In the manufacture of plasterboard, the stucco is first mixed with additives such as perlite, starch, fibreglass, or vermiculite. This mix is combined with water, soap foam, accelerators and shredded paper or pulpwood in a pin mixer at the head of a board forming line. The slurry is then spread between two paper sheets that serve as a mould. The edges of the paper are scored, and sometimes chamfered, to allow precise folding of the paper to form the edges of the board. As the wet board travels along a conveying line, the calcium sulfate hemihydrate combines with the water in the slurry to form solid calcium sulfate dihydrate, or gypsum, resulting in a rigid plasterboard. The board is cut to the desired length, and it enters a multideck dryer, where it is dried by direct contact with hot combustion gases or by indirect steam heating. The dried board is then bundled for shipment.

Gypsum used for agricultural purposes or as an additive to Portland cement is provided in its natural form, either as mined or after grinding.
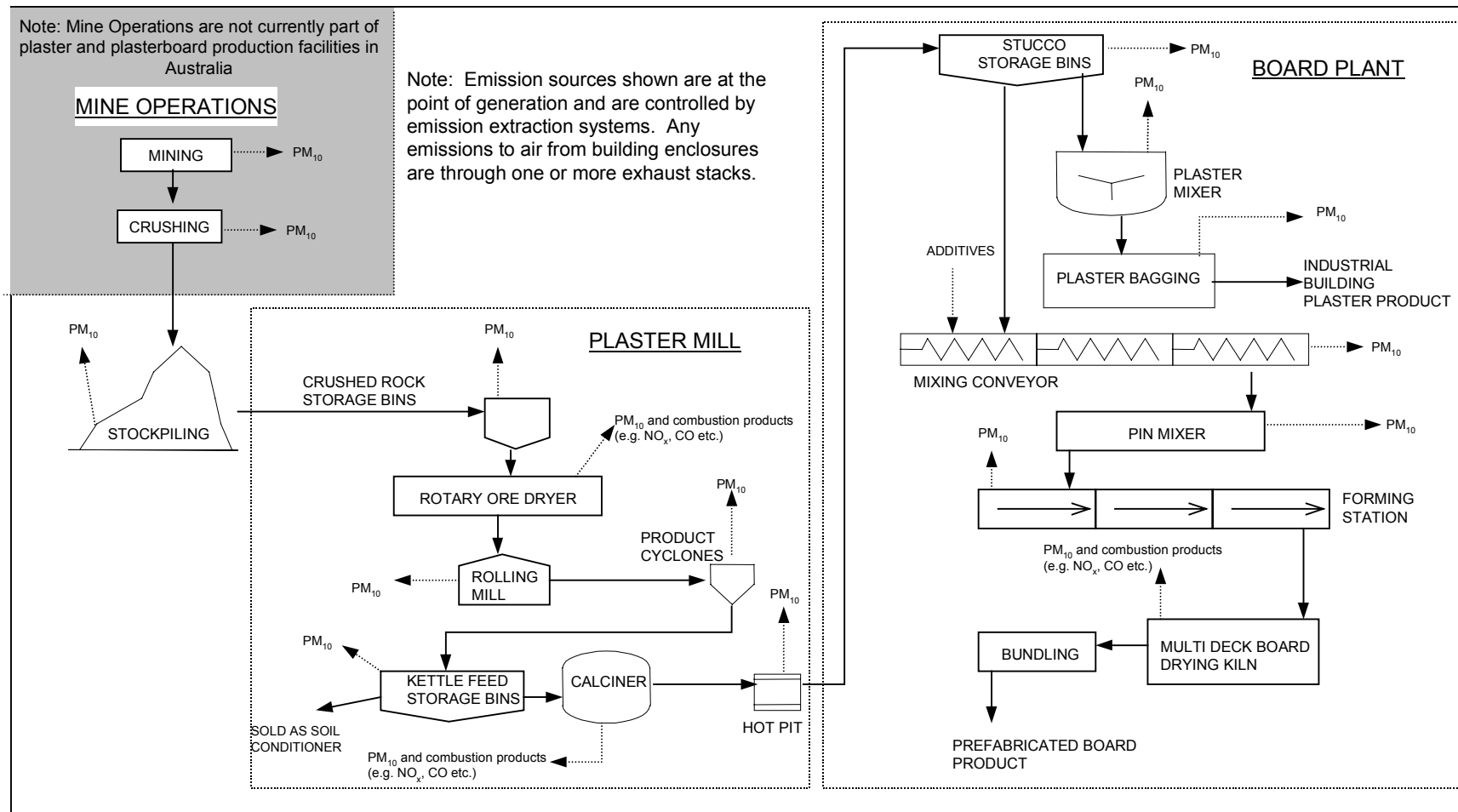
Figure 1 Process flow diagram of gypsum processing during Plasterboard and Plaster manuafacturing (Adapted by the Australian Gypsum Processing Industry from diagram in USEPA AP-42 Section 11.6 (1995))

Figure 2 shows the relationship between the Plaster Products Manufacturing Handbook and various NPI Emission Estimation Technique (EET) manuals and documents to assist in reporting to the NPI.
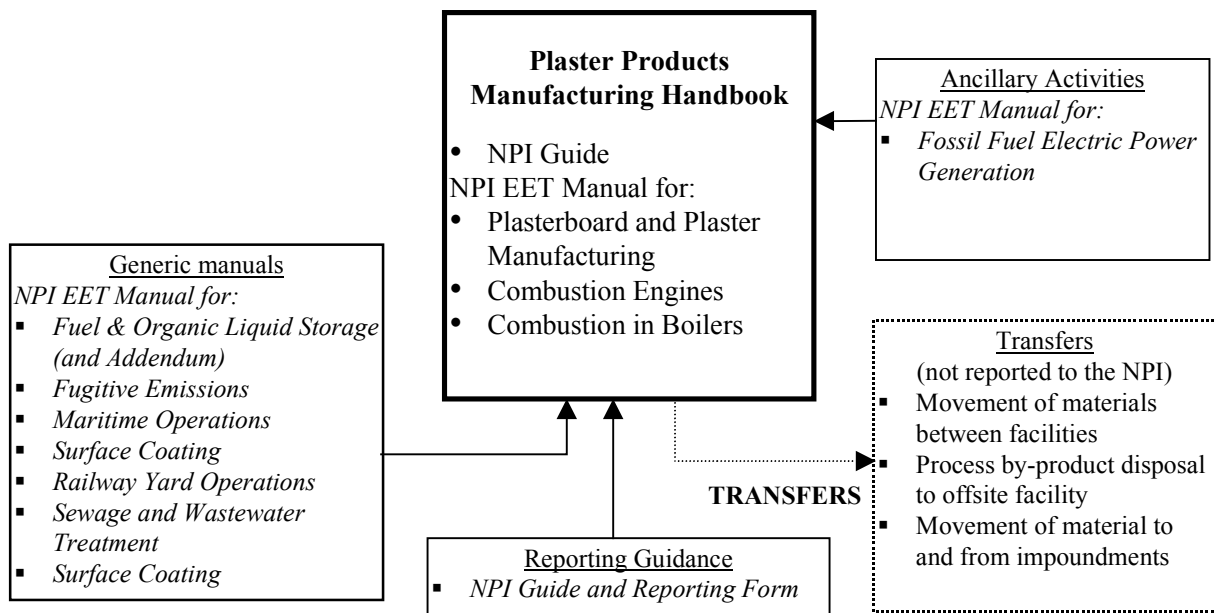
Note: The most recent versions of NPI documents from Internet site (www.npi.ea.gov.au) should be used. The documents are also available on CD-ROM.

Figure 2 The relationship between various NPI documents.

3.0 Emission Sources

Emissions from plaster manufacturing plants include combustion gases; wastewater; plant maintenance waste and research and laboratory wastes. Particulate matter from stacks is the largest emission stream. It is commonly collected in baghouses and is returned to the process. Steam is the largest emission from the manufacture of plasterboard.

Particulate matter (particles with an equivalent aerodynamic diameter of 10 micrometres or less i.e. $\leq 10\mu m$), oxides of nitrogen, sulfur dioxide, and carbon monoxide are the most likely listed substances emitted during the production of plaster and plasterboard.

3.1 Emissions to Air

Air emissions may be categorised as:

Fugitive Emissions

These are emissions that are not released through a vent or stack. Examples of fugitive emissions including vehicle emissions, dust from stockpiles, volatilisation from vats, open vessels, or spills and materials handling. Emissions emanating from ridgeline roof-vents, louvres, and open doors of a building as well as equipment leaks, and leaks from valves and flanges are also examples of fugitive emissions. Emission factor EETs are the usual method for determining losses through fugitive emissions.

Point Source Emissions

Particulate Matter (PM$_{10}$)

Sources of PM_{10} emissions at plasterboard and plaster plants include:

(1) raw material storage;

(2) milling and drying;

(3) calcination; and

(4) packaging and loading.

The largest emission source of PM_{10} for plasterboard and plaster plants can be found within the rotary ore dryers, grinding mills and calciners. PM_{10} emission factors for these operations are shown in Table 4 in Section 4.4.1. All of these emission factors are based on the dry gypsum processing rate.

Oxides of Nitrogen (NO$_x$)

NO_x are generated during fuel combustion by oxidation of chemically bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As the flame temperature increases, the amount of thermally generated NO_x also increases. The amount of NO_x generated from the fuel increases with the quantity of nitrogen in the fuel. In the plasterboard and plaster manufacturing process, NO_x is generated in both the burning zone of the calciners and dryers and the burning zone of the calcination vessel. Fuel use affects the quantity and type of NO_x generated. For example, in the calciner, natural gas combustion with a high flame temperature and low fuel nitrogen generates a larger quantity of NO_x than does oil or coal, which have a higher fuel nitrogen content but which burn with lower flame temperatures. The type of fuel used in the industry in Australia is natural gas.

Sulfur Dioxide (SO₂)

Sulfur dioxide may be generated both from the sulfur compounds in the raw materials and from the sulfur content of the fuel. The sulfur content of both raw materials and fuels varies depending on the facility and the location around Australia.

Organics

Fuel combustion can emit a wide range of organic pollutants in relatively small quantities. However possible pollutants from natural gas are restricted to NO_x, CO_2, and SO_2. If the combustion reactions do not reach completion, CO and aldehydes can be emitted.

3.2   Emissions to Water

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

* Surface waters (e.g. lakes, rivers, dams, and estuaries);

* Coastal or marine waters; and

* Stormwater.

Because of the significant environmental hazards posed by emitting toxic substances to water, most facilities emitting NPI-listed substances to waterways are required by their relevant State or Territory environment agency to closely monitor and measure these emissions. This existing sampling data can be used to calculate annual emissions. For the NPI, emissions to groundwater are classed as emissions to land.

The plasterboard and plaster manufacturing process generates wastewater from air pollution control equipment and the washdown of equipment and this is mostly sent to sewer. Some recycling and reuse of wastewater occurs through settling ponds and tanks. Wastewater generated by plaster manufacturing may not always contain NPI substances.

The transfer of NPI substances to a sewer or tailings storage facility does not require you to report to the NPI. Transfers are currently not reported to the NPI. However, leakage and other emissions of NPI substances, including PM_{10} or NPI substances contained in particulate matter, from engineered storage facilities are reported to the NPI if the appropriate reporting threshold is exceeded. See '*The NPI Guide*' for more details on determining NPI reporting thresholds.

3.3   Emissions to Land

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids and may contain listed substances. These emission sources can be broadly categorised as:

* surface impoundment of liquids and slurries;

* emissions to groundwater;

* unintentional leaks and spills; and

* stockpiles.

4.0   Emission Estimation Techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in *The NPI Guide* that is part of this Industry 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 EET (or mix of EETs) most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

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

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

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

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

You should note that the EETs presented in this Manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (e.g. 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, i.e. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

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

4.1 Sampling Data or 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.

Table 1 List of variables and symbols

Variable	Symbol	Units
Gypsum processing rate (Activity rate)	A	dry tonnes Gypsum/hour
Concentration	C	parts per million volume dry
Overall control efficiency[2]	CE_i	percent (%)
Filter catch	C_f	grams (g)
PM concentration	C_{PM}	grams/m^3
Emission factor	EF_i	typically kg/tonne of product
Emissions	E_i	typically kg/hr of pollutant i
Annual emissions	$E_{kpy,i}$	kg/year of pollutant i
Moisture collected	g_{moist}	grams
Moisture content	M	% , of pollutant i
Moisture in exhaust gas (wet)	$moist_R$	percent (%)
Molecular weight	MW	kg/kg-mole
Annual operating hours	$OpHrs$	hours/year
Flow rate	Q_a	actual cubic metres per second (m^3/s)
Flow rate	Q_d	dry standard cubic metres per second (m^3/s)
Fuel use	Q_f	typically, kg/hr
Temperature	T	degrees Celsius (°C)
Wind speed	U	m/sec
Molar volume @ STP (standard temperature and pressure)	V	22.4 m^3/kg-mole @ 0°C and 101.3 kPa
Metered volume at standard temperature and pressure	$V_{m, STP}$	m^3
Notes: 1. Source: Queensland Department of Environment and Heritage, 1998. 2. Some users may be accustomed to using Emission Reduction (ER)		

Stack sampling test reports often provide emissions data in terms of kg/hr or g/m^3 (dry standard). Annual emissions for NPI reporting can be calculated from this data using Equation 1 or Equation 2 overleaf. Stack tests for NPI reporting should be performed under representative (i.e. 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.

This section shows how to calculate emissions in kg/hr based on stack sampling data and how to convert this to an annual emissions figure. Calculations involved in determining PM$_{10}$ emissions are used as an example, although the same calculations are applicable for most of the substances listed on the Inventory.

With regards to emission controls for PM_{10}, in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

A generic example of test results is summarised in Table 2, these results do not relate specifically to the plaster industry, but rather demonstrate the methodology of the technique. 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 (Particulate Matter) concentration in grams per m^3. Note that this example does not present the condensable PM emissions.

Pollutant concentration determined by Equation 1 is multiplied by the volumetric flow rate, as outlined by Equation 2, to determine the emission rate in kilograms per hour as shown below.

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 of PM, 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, $g/dry\ m^3$ (from Equation 1)
Q_d = stack gas volumetric flow rate, m^3/s, dry
3.6 = unit conversion factor (3.6 kg/h = 1.0 g/s)
T = temperature of the gas sample, °C

Table 2 Stack Sample Test Results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (sec)		7 200	7 200	7 200
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[2] (m³/s)		1.67E-04	1.67E-04	1.67E-04
Standard metered volume (m³)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (m³/s), dry	Q_d	8.48	8.43	8.45
Concentration of particulate (g/m³)	C_{PM}	0.0718	0.0387	0.0537

Notes:
1. Source: Queensland Department of Environment and Heritage 1998.
2. Represents the rate of gas flow through the gas sampling apparatus.
3. Scientific notation is used; e.g. 7.38E-02 represents 7.38×10^{-2} or 0.0738.

Example 1 – Using stack sampling data

PM emissions calculated using Equation 1, Equation 2 and the stack sampling data for Test 1 from Table 2. The exhaust gas temperature is 150°C (423K).

From Equation 1:

$$C_{PM} = C_f / V_{m, STP}$$
$$= 0.0851 / 1.185$$
$$= 0.0718 \text{ g/m}^3 \text{ at } 150°C$$

Using the results from above Equation 2 used below determines the hourly emission rate of PM

$$E_{PM} = C_{PM} * Q_d * 3.6 * [273/(273+T)]$$
$$= 0.0718 * 8.48 * 3.6 * (273/423K)$$
$$= 1.41 \text{ kg/hr of PM}$$

The information from some stack tests may be reported in grams of particulate matter per cubic metre of exhaust gas (wet) and Equation 3 can be used to determine PM emissions (kg/hr) if the wet gas flow is known. Equation 3 is similar to Equation 2.

Equation 3
$$E_{PM} = C_{PM} * Q_a * 3.6 * [273/(273 + t)]$$

where:

E_{PM}	=	hourly emissions of PM in kilograms per hour, kg/hr
C_{PM}	=	concentration of PM or gram loading, g/m³ of actual (i.e. wet) gas flow (i.e. wet) at 0°C (273K)
Q_a	=	actual (i.e. wet) cubic metres of exhaust gas per second at temperature T, m³/s
3.6	=	unit conversion factor (3.6 kg/h = 1.0 g/s)
273	=	273 K (0°C)

       T   =   stack gas temperature, °C

If the exhaust gas flow is not known on an actual (wet) basis then the moisture content of the stack gas has to be considered to determine the actual gas flow. Equation 4 allows the calculation of stack gas moisture content.

> Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM_{10} from total PM emissions, it may be necessary for facility operators to first undertake a size analysis of the stack filter catch. The weight PM_{10} fraction can then be multiplied by the total PM emission rate to determine PM_{10} emissions. Alternatively, assume that 100% of PM emissions are PM_{10} (assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less i.e. ≤10μm).

Equation 4

$$moist_R = 100\% * \left(\frac{\left(\frac{V_{lc} * \rho_w}{M_w} \right) * \left(\frac{R * T_{STP}}{P_{STP}} \right) * 1000}{V_{MV,STP}} \right)$$

where

    $moist_R$ =   moisture content (volume of water vapour per unit volume of actual wet stack gas), vol%

    V_{lc} =   volume of liquid water collected, litres at STP

    ρ_w =   density of liquid water (0.9982 kg/l)

    $V_{MV,STP}$ =   wet metered volume of sample at STP, m^3

    R   =   ideal gas constant (8.314 J /K/ g-mol)

    T_{STP} =   standard temperature (273 K)

    P_{STP} =   standard pressure (101 300 Pa (i.e. 1 atm))

    M_W =   molecular weight water (18.0 g/g-mol)

    1000   =   conversion factor from g to kg (i.e. 1kg = 1000g)

Example 2 – Calculating moisture percentage using the data from Table 2.

From test 1 in Table 2 a 1.185 m^3 sample of gas at STP contains 395.6 g of water. To calculate the moisture percentage use Equation 4.

$$\text{moist}_R = 100\% * \left(\frac{\left(\frac{V_{lc} * \rho_w}{M_w} \right) * \left(\frac{R * T_{STP}}{P_{STP}} \right) * 1000}{V_{MV,STP}} \right)$$

Note the $V_{lc} * \rho_w$ term is equivalent to the weight of water collected and in this example the weight is 0.3956 kg.

R * T$_{STP}$/P$_{STP}$ =   8.314*273 / 101 300
                                           =   0.0224 m^3/g-mol

moist$_R$ =   [0.3956 kg/18 g/g-mol*0.0224 m^3/g-mol*1000 g/kg]/1.185 m^3
                                           =   41.5 vol %

4.1.1 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.

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 calciner. Emission rates (kg/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 3 presents example CEM data output for three periods for a hypothetical calciner. 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 calciner operation. While it is possible to determine total emissions of an individual pollutant over a given time period from this data, assuming the CEM 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.

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 emissions estimations.

Table 3 Example of CEMS Output for a typical mill exhaust gas stream for a process using natural gas.

Test	Time	Concentration (mg/Nm³)				Stack Gas Flow (Q) Nm³/min	Average Dry Gypsum Rate (A) (tonnes/hour)
		SO_2^1	NO_x^2	CO^1	VOC^2		
1	1530	<3				3 300	23.6
2	1740	<3				3 300	23.6
1	1510		13			3 300	23.6
2	1610		7.2			3 300	23.6
1	1630			32		3 300	23.6
2	1636			28		3 300	23.6
1	1510				<2	3 300	23.6
2	1545				<2	3 300	23.6
Notes:							
1. Reference 1: Plasterboard Industry NPI Emission Monitoring Programme page 50 Table 18.							
2. Reference 1: Plasterboard Industry NPI Emission Monitoring Programme page 49 Table 17.							
3. The operating hours for the year were 6344 hr.							

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

Equation 5

$$E_i \quad = \quad C * Q * 60 / 10^6$$

where:

E_i = emissions of pollutant i, kg/hr
C = pollutant concentration, mg/Nm³
Q = stack gas volumetric flow rate, Nm³/min
10^6 = conversion factor (i.e. 1 kg = 10^6 mg)

If the concentration of pollutant is determined in units other than those in Table 3 then Equation 5 needs adjusting accordingly.

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 adding the results.

Equation 6

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

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 dry gypsum processed can be calculated by dividing the emission rate in kg/hr by the activity rate (gypsum processing rate, tonnes/hr)

during the same period as shown in Equation 7. It should be noted that the emission factor calculated below assumes that the selected time period (i.e. hourly) is representative of annual operating conditions and longer time periods should be used for NPI reporting where they are available. Example 3 illustrates the application of Equation 5, Equation 6 and Equation 7.

Example 3 – Using CEMS Data

This example shows how CO emissions can be calculated using Equation 5 based on the CEMS data in Table 3. The processing units operate for 6344 hours per year and process 150 000 tonnes of dry gypsum per year.

Use the highest concentration value.

$$E_{SO2,1} = C * Q * 60 / 10^6$$
$$= 32 * 3\ 300 * 60 / 10^6$$
$$= 6.34 \text{ kg/hr}$$

The operating hours for the year at these operating conditions are 6344 hours.

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

$$E_{kpy,SO2} = E_{CO} * OpHrs$$
$$= 6.34 \text{ kg/hr} * 6344 \text{ hr/yr}$$
$$= 40\ 221 \text{ kg/yr}$$

The dry gypsum processing rate = (150 000 tonnes/year)/(6 344 hr/year)
= 23.6 tonnes/hr dry gypsum

Emissions, in terms of kg/tonne of gypsum processed can be calculated using Equation 7.

$$E_{kpt,CO} = E_{CO} / A$$
$$= 6.34 / 23.6$$
$$= 0.269 \text{ kg CO emitted per tonne of dry gypsum processed}$$

Equation 7

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

where:

$E_{kpt,i}$ = emissions of pollutant i per tonne of dry gypsum processed, kg/t
E_i = hourly emissions of pollutant i, kg/hr
A = dry gypsum processing rate, t/hr

4.2   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.

4.3   Engineering Calculations

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

4.3.1 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 mass conservation laws, if fuel use 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, which is typically converted to SO_2, an NPI substance, during the combustion process. This technique can be used for all fuels including; coal, oil and natural gas. Natural gas is the fuel used by the gypsum processing industry currently.

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

Equation 8

$$E_{kpy,i} = Q_f * \text{pollutant concentration in fuel} * (MW_p / EW_f) * OpHrs$$

where:

$E_{kpy,i}$	=	hourly emissions in kg per hour of pollutant i, kg/h
Q_f	=	fuel use, kg/hr
MW_p	=	molecular weight of pollutant emitted, kg/kg-mole
EW_f	=	elemental weight of element in fuel, kg/kg-mole
$OpHrs$ =		operating hours, hr/yr

For instance, SO_2 emissions from natural gas combustion can be calculated based on the concentration of sulfur in the natural gas. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every kilogram of sulfur (elemental weight, EW = 32) burned, two kilograms of SO_2 (MW = 64) are emitted. The application of this EET is shown in Example 4.

> **Example 4 – Using Fuel Analysis Data**
>
> This example illustrates how SO_2 emissions can be calculated from natural gas combustion based on fuel analysis results and the fuel flow information from the plaster and plaster board process. The plaster and plasterboard process uses 400 million (4.00E+08) MJ of Natural Gas per year. The annual emissions may be calculated using a similar approach as in Equation 8.
>
> $E_{kpy,SO2} = Q_f$ * pollutant concentration in fuel * (MW_p / EW_f) * OpHrs
>
> | | | |
> |---|---|---|
> | Fuel flow | = | 4.00E+08 MJ/year |
> | Sulfur level in fuel | = | 8.5 mg/Sm^3 (typically ranges from 7 to 10 mg/Sm^3) |
> | Calorific Value of Natural Gas | = | 38.9 MJ/Sm^3 (as in NPI Guide version 2.1 – 18 December 2000) |
> | EW_S | = | 32 g/gmol |
> | MW_{SO2} | = | 64 g/gmol |
>
> $$E_{kpy,SO2} = Q_f \text{ * pollutant concentration in fuel * } (MW_p / EW_f)$$
> $$= (4.00+E+08 \text{ MJ/year})/(38.9 \text{ MJ/Sm}^3)*(8.5 \text{ mg/Sm}^3)*$$
> $$(1.00E\text{-}06 \text{ kg/mg}) *(64 / 32)$$
> $$= 1.75E+02$$
> $$= 175 \text{ kg/yr } SO_2$$
>
> Note:
> 1. The OpHrs term is not required because the natural gas use is on an annual basis.
> 2. If there are emissions of sulfur dioxide from other sources at the facility, for example vehicles, the estimate of these emissions needs to be added to the estimate above when reporting to the NPI.

4.4   Emission Factors

An emission factor is a tool that is used to estimate emissions to the environment. In this Manual, it relates the quantity of substances emitted from a source related 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 (e.g. kilograms of sulfur dioxide emitted per tonne gypsum processed). Sources for all emission factors cited can be found in the reference list, section 6.0, at the back of this Manual. The emission factor ratings <u>will not</u> form part of the public NPI database.

When using emission factors, you should be aware of the associated emission factor rating (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

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

Equation 9

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

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 emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

4.4.1 Industry-Wide Emission Factors

The gypsum processing industry in Australia have completed extensive test work to develop emission factors relevant to the industry in Australia. These emission factors are listed in Table 4. Example 5 illustrates the use of the emission factors in Table 4 to estimate emissions from the gypsum processing plant of a facility. The emission factors listed in do not include the estimation of emissions from other sources that operate on the facility such as emissions from vehicles.

Table 4 Emission factors for NPI substances emitted from gypsum processing plant operations

Substance Emitted	Emission Factor [1]	Substance Emitted	Emission Factor [1]
Ammonia (total)	3.08E-03	Hydrochloric acid	9.41E-06
Antimony & compounds	0	Lead & compounds	7.85E-05
Arsenic & compounds	0	Magnesium oxide fume[3]	0
Beryllium & compounds	0	Manganese & compounds	2.51EE-03
Boron & compounds	1.44E-03	Mercury & compounds	0
Benzene	0	Nickel & compounds	2.24E-04
Cadmium & compounds	0	Oxides of Nitrogen (NO_x)	1.31E-01
Carbon monoxide	7.78E-01	Particulate matter less than of equal to 10.0 microns (PM_{10}) – from stacks only	7.07E-02
Chlorine	0	Polychlorinated dioxins and furans (TEQ)[4]	8.01E-10
Chromium (III) compounds[5]	7.38E-05	Polycyclic Aromatic Hydrocarbons (PAHs)	6.31E-05
Chromium (VI) compounds[5]	0	Selenium & compounds	0
Cobalt & compounds	0	Sulfur dioxide	2.07E-02
Copper & compounds	5.42E-05	Total Volatile Organic Compounds (VOC)	5.60E-03
Ethylbenzene	0	Xylene (individual or mixed isomers)	0
Formaldehyde (methyl aldehyde)	7.13E-03	Zinc & compounds	4.37E-04

Notes:
1. Derived from direct analysis data contained in Reference 1 by AWN Consultants and units are kg/dry tonne of Gypsum.
2. Emission factors above are determined from measurements post emission control equipment that is part of the process. Typical emission control equipment used is baghouses (fabric filters).
3. Magnesium compounds are released from the plaster manufacturing process, however not in the form of the NPI substance MgO.
4. For the NPI, polychlorinated dioxins and furans are reported in terms of toxic equivalence (TEQ), which is a means of scaling the emissions of each species of dioxins and furans according to their relative toxicity. The most toxic substance is 2,3,7,8-tetrachlorodibenzodioxin (2,3,7,8-TCDD), and it is assigned a toxic equivalence factor (TEF) of One (1); other dioxins and furans are assigned TEFs relative to this value. To calculate the TEQ emitted from a source, the measured quantity of each of the dioxin and furan compounds is multiplied by its assigned TEF. The results are then summed to produce a single TEQ value. See Reference 1 for more details.
5. The naturally occurring form of Chromium compounds in ores and refractories is as Chromite ($FeCr_2O_4$) which is a Cr (III) compound. Until further work is completed on the issue the emissions of Chromium from the plaster industry will be assumed to be Cr (III) compounds. The chromium from the plaster industry is expected to come from the furnace refractory material that is in the form of the mineral Chromite.
6. The emission factors were determined from examining emissions from a typical plaster processing plant in Australia with appropriate cross checks for some substances with two other Australian facilities.
7. The emission factor rating is B for all substances in this table. See section 4.4 for details.
8. Scientific notation is used; e.g. 7.38E-02 represents 7.38×10^{-2} or 0.0738 and 7.38E+02 represents 7.38×10^{2} or 738.

Example 5 – Using Emission Factors

Table 4 shows that 7.78E-01 kg of carbon monoxide are emitted for each tonne of dry gypsum processed by a typical Australian plant. It is assumed that the plant operates for 8 000 hours per year.

$$CE_{CO} \quad = \quad 0 \text{ (since } EF_{CO} \text{ is a controlled figure)}$$
$$EF_{CO} \quad = \quad 7.78\text{E-01 kg/t of dry gypsum (or 0.778 kg/t)}$$

dry gypsum
processing rate $\quad = \quad$ 12 t/hr

$$E_{kpy,CO} \quad = \quad [A * OpHrs] * EF_{CO} * [1 - CE_i/100]$$
$$= \quad [250 \text{ t/hr} * 1500 \text{ hr/yr}] * 0.008 \text{ kg/t} * [1 - 0/100]$$
$$= \quad 3000 \text{ kg/yr}$$

Notes:
1. If there are emissions of carbon monoxide from other sources at the facility, for example vehicles, the estimate of these emissions needs to be added to the estimate above when reporting to the NPI.
2. Reporting estimates of emissions of a substance to the NPI is only required if the reporting threshold for the substance is exceeded. See the NPI Guide for more information.

4.4.2 Emission Factors for PM_{10} for Gypsum Processing

Emissions of PM_{10} from the various activities in plasterboard and plaster production may be calculated using the following information:

Materials Handling

a)   unenclosed activities completed outdoors

Equation 10
$$E_{PM10} \quad = \quad 0.75 * 0.001184 * [(U/2.2)^{1.3} / (M/2)^{1.4}] * [1-CE_i/100]$$
where:

$$E_{PM10} \quad = \quad \text{emission factor, kg of } PM_{10} \text{ /tonne of material handled}$$
$$U \quad = \quad \text{mean wind speed, m/sec}$$
$$M \quad = \quad \text{mean moisture content of material, t/t}$$
$$CE_i \quad = \quad \text{overall control efficiency, \%, Table 5}$$

Note: For materials where M = 0, use default of 3.6 % (0.0036 t/t) handled. The moisture content of gypsum is typically 3-4%, so a default value of M above is 3.6%.

Table 5 Overall Control Efficiencies[2] for Materials Handling and Storage

Control Method	Reduction Factors (ER)	Control Efficiency (CE)
- wind breaks	0.7	30%
- water sprays	0.5	50%
- chemical suppression	0.2	80%
- enclosure (2 or 3 walls)	0.1	90%
- covered stockpiles	0.0	100%

Notes:
1. Reference 2: The Cement Industry Federation Limited, 1998.
2. Some users may be accustomed to using Emission Reduction Factors in similar calculations. A Reduction Factor (ER) of 0.2 equates to a control efficiency (CE) of 80%.
3. $ER = (1-CE/100)$.

In this situation from Table 5 the overall control efficiency is 100% and hence Equation 10 becomes:

$$E_{PM10} = 0.0$$

Materials Storage

Wind erosion from active stockpiles emissions (kg/ha-area/hr of base) can be calculated using the following equation:

Equation 11
$$E_{PM10} = EF_{PM10} * Area * (1 - CE_i/100)$$

where:

E_{PM10} = emissions (kg/hr)
EF_{PM10} = emission factor (kg/area of base of stockpile/hour)
Area = area of base of stockpile in hectares
CE_i = overall control efficiency, %, Table 5

In the absence of available PM_{10} data, use EF_{PM10} = 0.3 kg/ha/hr

To determine the annual emission multiply the PM_{10} emission factor (E_{PM10}) by the number of hours in a year (8 760) as in Equation 12.

Equation 12

$$E_{kpy,PM10} = E_{PM10} * YHr$$

where:

$E_{kpy,PM10}$ = Annual emission of PM_{10}, (kg/y)
E_{PM10} = PM_{10} emission factor from Equation 11, (kg/hr)
YHr = Hours per year, (8 760 hr/yr)

Example 6 – Stockpile Emissions

A stockpile with a half-hectare base is active for the full year. Emissions of PM_{10} are calculated using Equation 11. No information is available on site-specific factors hence the default emission factor is used. Water sprays are used to suppress dust, see Table 5.

Hourly emissions	E_{PM10}	$=$	$EF_{PM10} * Area * CE_i$
		$=$	$0.3 * 0.5 * (1-50/100)$
		$=$	0.075 kg/hr

Annual emissions	$E_{kpyPM10}$	$=$	$E_{PM10} * YHr$
		$=$	$0.075 * 8760$
		$=$	657 kg/year

4.4.3   Vehicle Traffic

For Australian plasterboard and plaster manufacturing facilities vehicles mainly travel about the facility on sealed roads and surfaces. The emissions from vehicle engines should be estimated from the most recent version (2.1 as at June 2001) of the NPI combustion engines EET manual. If the reporting threshold of a substance is exceeded then the estimate of the emissions from all sources have to be reported to the NPI.

For vehicles with a gross mass greater than 5 tonnes operating on <u>unsealed</u> roads use the equation in the latest version of the NPI Mining Manual. Equation 13 details the estimation of total vehicle kilometres travelled per year (VKT).

Equation 13

Number of vehicles *   Kilometre travelled   =   Total vehicle kilometres
On-site (vehicles)   per vehicle per year   travelled per year (km/yr)
                                         (km/(vehicle-yr))

Example 7 – Calculating VKT

A reporting facility has five trucks that each travel approximately 1000 kilometres on-site per year. Using Equation 13:

Number of vehicles * kilometre travelled per vehicle per year = VKT

5 vehicles * 1000km/(vehicle-yr) = 5000km/yr

Therefore, total VKT = 5000km/yr

4.4.4 Predictive Emission Monitoring (PEM)

Predictive emission monitoring is based on developing a correlation between pollutant emission rates and process parameters. A PEM allows facilities to develop site-specific emission factors, or emission factors more relevant to their particular process.

Based on test data, a mathematical correlation can be developed which predicts emissions using various parameters.

4.5 Control Technologies

Air emission control technologies, such as fabric filters (also called baghouses), are commonly installed to reduce the concentration of particulates in process off-gases before stack emission. Where such emission abatement equipment has been installed, and where emission factors from uncontrolled sources have been applied in emission estimation, the collection efficiency of the abatement equipment needs to be considered. Guidance on applying collection efficiencies to emission factor equations is provided in earlier sections.

A fabric filter or baghouse is a large sealed unit containing a series of fabric bags. The process gas containing particulate material enters one side of the unit and the particulate matter is trapped in the fabric bag with clean gas leaving the other side. Intermittently the particulate material is removed from the fabric bag by some mechanism such as shaking or pulsing. The particulate material is collected and in the gypsum processing industry recycled back into the process.

With regards to emission controls for PM_{10}, in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

It is important to note that emission control devices are frequently needed to collect the product from some plasterboard and plaster processes and are therefore commonly thought of by the industry as process equipment and not as added control devices.

Emission sources in plasterboard and plaster plants, as shown in Table 6, are most often controlled by fabric filters.

Table 6 Emission Sources Controlled by Fabric Filters in Plasterboard and plaster Plants

Typical Emission Sources		
Rotary ore dryers	Kettle calciners	Plaster mixing and bagging
Roller mills	Flash calciners	Conveying systems
Impact mills	Scoring and chamfering	Storage bins
Notes: 1. Source : Qld Department of Environment and Heritage 1998.		

Uncontrolled emissions from some external conveying systems are not well quantified. In some cases, transfer points in particular, particulate emissions are controlled by fabric filters.

Abatement equipment and control technologies, such as baghouses and fabric filters are often used to reduce emissions in the plasterboard and plaster industry. If these, or other abatement equipment, are installed at your facility, or if you have implemented work practices at your facility that reduce emissions, you should multiply the control efficiency of the technology or the practice adopted, by the appropriate emission factors used in Section 4.4.

5.0 Glossary of Technical Terms and Abbreviations

Table 7 Glossary of Technical Terms and Abbreviations used in this Manual

Term	Definition
CE	Control Efficiency
CEMS	Continuous Emission Monitoring Systems
EET	Emission Estimation Technique
EFR	Emission Factor Rating
ER	Reduction Factor
NEPM	National Environment Protection Measure
NO_x	Oxides of Nitrogen
PEM	Predictive Emission Monitoring
PM	Particulate Matter – equivalent to TSP
PM_{10}	Particulate matter less than or equal to 10 microns in diameter
SO_2	Sulfur dioxide
TSP	Total Suspended Particulates – equivalent to PM
VKT	Vehicle Kilometres Travelled per year
VOC	Total volatile organic compounds

6.0   References

1. Air Water Noise, 28 February 2001. *Plasterboard Industry NPI Emission Monitoring Programme.* Report No. B128 – December – January 2001. Copy in Environment Australia library.

2. Cement Industry Federation. 1998. Written Communication with the Cement Industry Federation.

3. Eastern Research Group. July 1997. *Introduction To Stationary Point Source Emission Inventory Development Volume II: Chapter 1.* Morrisville, NC, USA.

4. EMEP/CORINAIR. (1996). *AIR: Atmospheric Emission Inventory Guidebook.* European Environment Agency, Copenhagen, Denmark.

5. USEPA. September 1995. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fourth edition, AP-42. Section 11.6 Mineral Products Industry.* 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

6. USEPA. September 1995. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fourth edition, AP-42. Section 13.2 Miscellaneous Sources.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.

7. USEPA. September 1995. *EPA Office of Compliance Sector Notebook Project. Profile of the Stone, Clay, Glass, and Concrete Products Industry.* United States Environmental Protection Agency, Office of Enforcement and Compliance Assurance. Washington, DC, USA.

The following Emission Estimation Technique Manuals referred to in this Manual are available on the NPI Homepage www.npi.gov.au and from your local environmental protection agency (see the front of the NPI Guide for details):

- Emission Estimation Technique Manual for Combustion Engines;
- Emission Estimation Technique Manual for Cement Manufacturing; and
- Emission Estimation Technique Manual for Lime & Dolomite Manufacturing.