



Australian Government

Department of the Environment, Water, Heritage and the Arts



National Pollutant Inventory

**Emission estimation
technique manual
for**

Alumina refining

Version 2.0

November 2007

First published in March 1999

ISBN: 0642 549273

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**EMISSION ESTIMATION TECHNIQUES
FOR
ALUMINA REFINING
TABLE OF CONTENTS**

DISCLAIMER	I
1 INTRODUCTION.....	1
1.1 The process for NPI reporting.....	1
1.2 Information required to produce an annual NPI report.....	2
1.3 Additional reporting materials	2
2 PROCESS DESCRIPTION AND TYPICAL EMISSIONS.....	3
2.1 Identification of industry emissions	3
2.1.1 Combustion sources.....	3
2.1.2 Aggregate handling and storage	3
2.1.3 Bulk chemical handling and storage.....	5
2.1.4 Bauxite processing.....	5
2.1.5 Drying/calcining	6
2.1.6 Spent process material storage	6
2.1.7 Maintenance and support functions.....	7
3 EMISSION SOURCES	8
3.1 Emissions to air	8
3.1.1 Fugitive emissions	8
3.1.2 Point source emissions	13
3.2 Emissions to water	14
3.3 Emissions to land	16
3.3.1 Groundwater monitoring	16
3.3.2 Spills	17
3.3.3 On-site disposal	18
4 THRESHOLD CALCULATIONS	19
5 TECHNIQUES FOR ESTIMATING EMISSIONS	25
5.1 Direct measurement.....	25
5.2 Emission factors	27
5.3 Mass balance	28
5.4 Approved alternative.....	28
6 TRANSFERS OF NPI SUBSTANCES IN WASTE.....	29
7 NEXT STEPS FOR REPORTING	30
8 REFERENCES.....	31
APPENDIX A: ABBREVIATIONS AND DEFINITIONS	32
APPENDIX B: EMISSION FACTORS	33
APPENDIX C: PROCESS DESCRIPTION	34
APPENDIX D: MODIFICATIONS TO THE ALUMINA REFINING EMISSION ESTIMATION TECHNIQUE (EET) MANUAL (VERSION 1.1 OCTOBER 2007)	36

ALUMINA REFINING

LIST OF FIGURES, TABLES, EQUATIONS AND EXAMPLES

Table 1:	Speciation of VOCs which are NPI substances ¹	11
Table 2	Acid Properties ¹	11
Table 3	Speciation data for alumina refining ^{1, 2, and 3}	13
Table 4	Measurement data	15
Table 5	NPI substances	20
Figure 1	Alumina refinery process flow diagram	4
Equation 1	.....	9
Equation 2	.....	10
Equation 3	.....	10
Equation 4	.....	11
Equation 5	.....	12
Equation 6	.....	13
Equation 7	.....	17
Equation 8	.....	17
Equation 9	.....	27
Example 1	Emissions of PM ₁₀ from a wet scrubber with a control efficiency of 90 wt%... 9	
Example 2	NPI emissions from a wastewater stream	14
Example 3	Cadmium and compounds emissions to water based on regular monitoring of wastewater from a facility	15
Example 4	Emissions determined by direct measurement: emission factor units are the same as the process flow units	26
Example 5	Emissions determined by direct measurement: emission factor units are different from the process flow units	26

1 Introduction

The purpose of all emission estimation technique (EET) manuals 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 alumina refining activities.

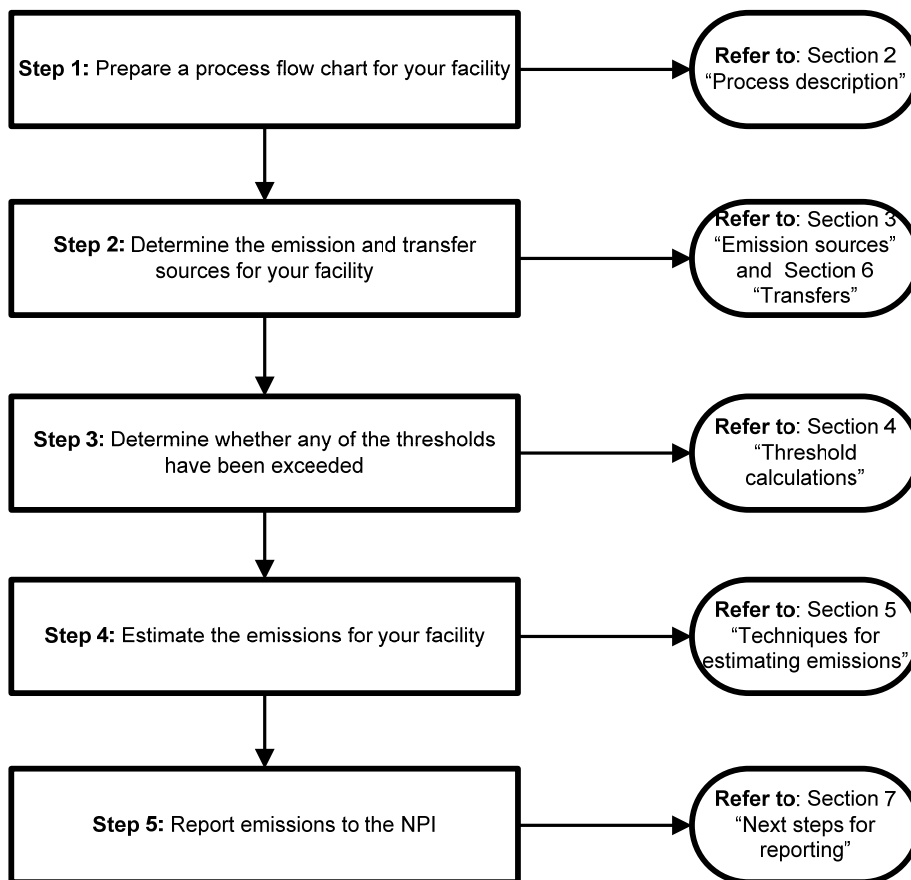
EET MANUAL Alumina refining
ANZSIC (2006)CODE 2131 Alumina production

Note that the ANZSIC code is part of NPI reporting requirements. *The NPI Guide* contains an explanation of the ANZSIC code.

This manual has been developed through a process of national consultation involving state and territory environmental authorities and key industry stakeholders. Particular thanks are due to the Australian Aluminium Council and members for their assistance in developing this manual.

1.1 The process for NPI reporting

The process for NPI reporting can be seen in the following flow chart:



The alumina refining activities covered by this manual include:

- raw material handling and storage
- bauxite processing (including grinding, digesting, precipitating, and drying), *and*
- ancillary operations including descaling, residue storage, and associated maintenance activities.

1.2 Information required to produce an annual NPI report

If any fuel burning equipment has been used on the facility, including boilers, furnaces and/or on-site vehicles, additional data will need to be collated:

- type and amount of fuel burned
- pollution control devices employed, *and*
- volume and throughput of fuels or organic liquids stored on site.

1.3 Additional reporting materials

This manual is written to reflect the common processes employed in alumina refining. In many cases it will be necessary to refer to other EET manuals to ensure a complete report of the emissions for the facility can be made. Other applicable EET manuals may include, but are not limited to:

- Combustion in boilers
- Combustion in engines
- Fuel and organic liquid storage
- Fugitive emissions *and*
- Mining

2 Process description and typical emissions

The first step in working out the emissions of NPI substances from your facility is creating a process flow diagram to highlight points in the process where emissions may occur.

The figure on the next page presents a brief flow chart for alumina refining, and identifies the likely sources of emissions. A detailed process description is included in Figure 1.

This represents a typical facility in the industry, but you should develop a process flow diagram specific to your site.

2.1 Identification of industry emissions

The NPI substances emitted (or expected to be emitted) from the various activities associated with alumina refining result from:

- combustion sources: boilers, furnaces and on-site vehicles
- aggregate storage and handling
- bulk chemical handling and storage
- bauxite processing
- drying/calcining
- spent material storage *and*
- maintenance and support functions.

2.1.1 Combustion sources

Many facilities generate heat (for further use in the process), energy and/or steam on-site through combustion of natural gas, fuel oil, and/or coal. These activities will result in emissions of NPI substances, and therefore must be considered in an NPI report.

2.1.2 Aggregate handling and storage

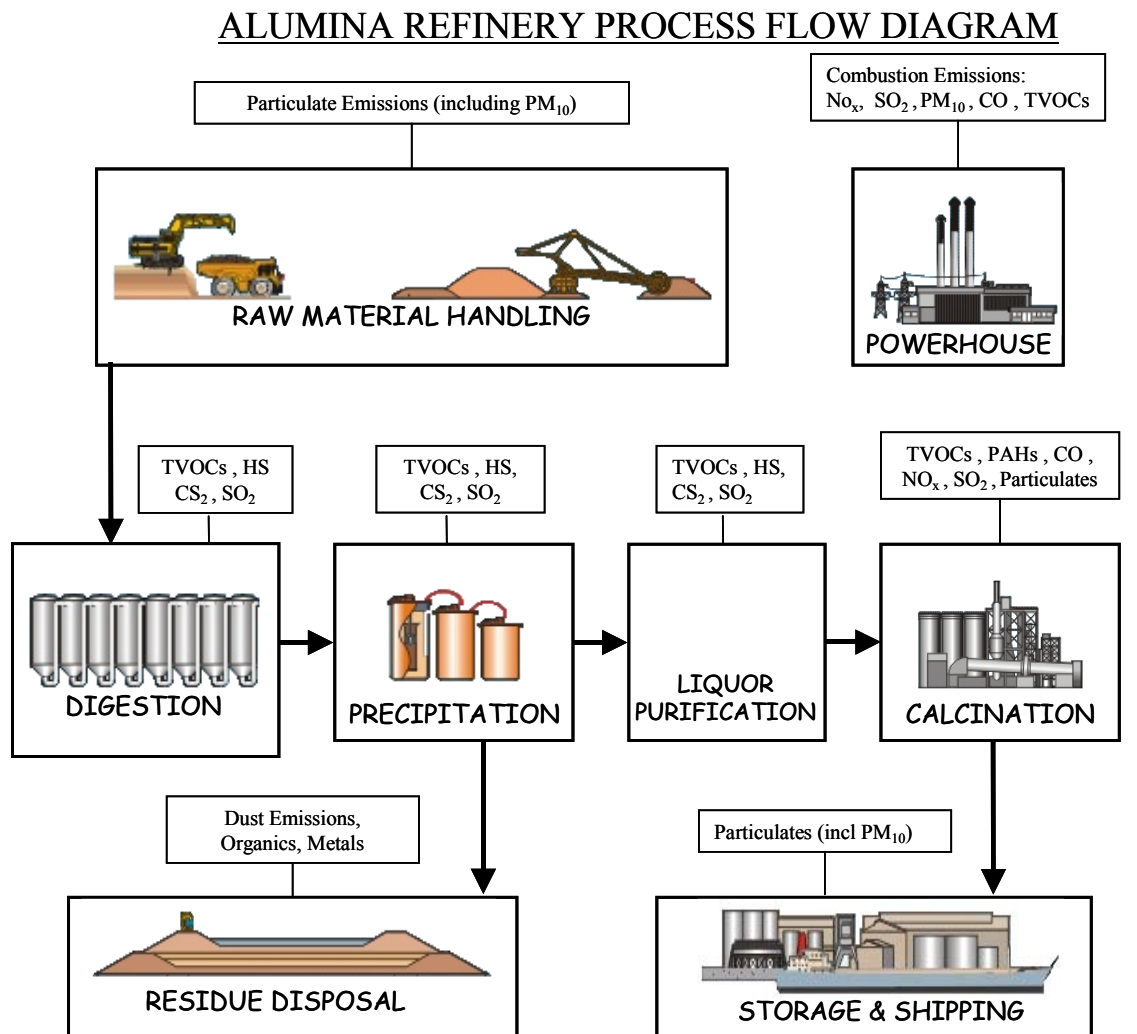
2.1.2.1 Bauxite

Bauxite is transported from the carrier (such as a marine vessel), or directly from the bauxite mine to the site storage via conveyor. The material is stockpiled on site and transported to the bauxite processing area for refining into alumina. While each facility may have a different process configuration, a typical bauxite handling and storage scenario would include the following:

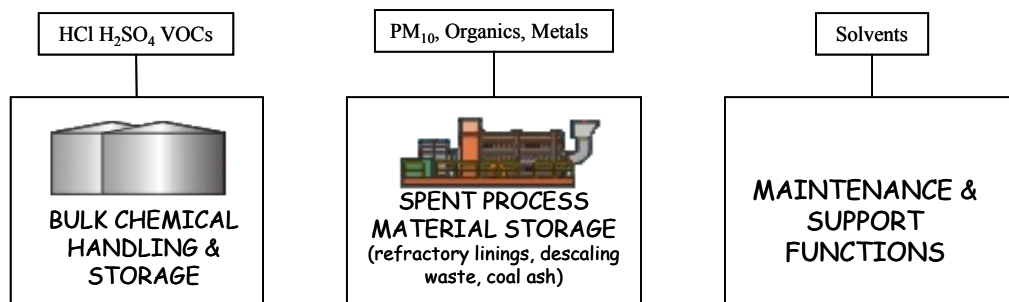
- unloading or transporting to processing site via conveyer
- stockpiling
- conveying from stockpile to bauxite processing.

Potential NPI emissions are discussed in Section 3.

Figure 1 Alumina refinery process flow diagram



OTHER RELEVANT PROCESSES



Note: Process emissions listed above are to be used as a guide only. Actual emissions may vary from site to site

2.1.2.2 Limestone and other aggregate

Lime or limestone is transported to the facility and stockpiled. A typical scenario would include the following:

- unloading
- stockpiling *and*
- conveying to bauxite processing.

2.1.3 Bulk chemical handling and storage

Bulk chemicals stored on site in tanks for use in the process may include:

- biocides
- chlorine
- defoamer
- diesel
- flocculants
- hydrochloric acid
- liquefied petroleum gas (LPG)
- petrol, *and*
- sulfuric acid.

Note: Other Category 1 substances may also be used in quantities that may trip the 10 tonne NPI reporting threshold. These will need to be identified and included in calculations to determine if the threshold has been exceeded for that substance.

As indicated in Table 5, these substances may be released to air. However, there is also the potential for emissions to land from spills.

For information on emission estimations for fuel oil and organic liquid storage, refer to the *Fuel and Organic Liquid Storage* manual (www.npi.gov.au).

2.1.4 Bauxite processing

Bauxite processing includes grinding, digestion, drying and calcining. These processes give rise to air emissions and the formation of spent process material.

2.1.4.1 Grinding

The bauxite is crushed and finely ground in a mill prior to the digestion process. The grinding process gives rise to air emissions as indicated in Section 3.1.1. The use of a control technology, such as a spray tower, floating bed scrubber, or cyclone, can help reduce particulate emissions. Where grinding is carried out using wet milling, minimal dust emissions would be expected.

2.1.4.2 Digestion

Finely ground bauxite is mixed with sodium hydroxide solution and lime to form slurry, and reacted at high pressure and temperature to remove the iron oxides and most of the silicon oxides. The pressure, temperature and retention time in the digester is a function of the mineral composition of the bauxite. Sodium aluminate is formed, and the silicon, iron, titanium and calcium oxides form the insoluble components of the solid waste residual.

During the digestion process, volatile organic components from the ore are vented and emitted to air. Table 5 provides a list of possible NPI substances emitted from the digestion process.

2.1.4.3 Precipitation and clarification

The hot slurry is usually cooled by flash evaporation, producing steam that is used to preheat the incoming slurry. The slurry is then processed in a series of clarification steps designed to separate the solid residual from the liquor. The steps can include the following:

- passage of slurry through hydrocyclones to remove grit
- addition of flocculants (i.e. starch or other settling agents) to settle fine particles
- filtration of clear overflow
- washing of underflow with thickeners to remove caustic agents, which is then sent on as spent product
- sending of filtrate (containing sodium aluminate) to precipitator, *and*
- crystallisation and precipitation of aluminium hydroxide.

Table 5 shows NPI substances that are emitted from the precipitator. The precipitator may also give rise to fugitive emissions of volatile organic substances similar to the substances identified for the digester.

2.1.4.4 Classification

After precipitation, the slurry (containing trihydrate crystals) is sent to classification where the product is classified according to crystal size. The coarse particles are:

- washed to remove excess sodium hydroxide
- dewatered on vacuum filters, *and*
- sent to calcination.

The finer crystals are recycled to the precipitation process as seed crystals, thereby providing nucleation sites for precipitation to occur. Spent liquor from the precipitators is recycled to the digesters.

2.1.5 Drying/calcining

The coarse alumina is calcined in rotary kilns or fluid-bed calciners at about 1000 °C. During calcination, water and other volatile compounds are driven off. Calciners produce hot flue gases containing alumina and water vapour. Two types of kilns are used in the refining industry: oxalate and liquor burning. Carbon monoxide is produced in the oxalate process.

Typical control equipment includes cyclonic separators followed by electrostatic precipitators (ESPs). The control equipment can also be used to recover product as well as minimise emissions. You should note that the emissions associated with this activity depend on the specific fuel being used.

2.1.6 Spent process material storage

The following spent process material is generated during the refining process:

- red mud from precipitator and clarifier
- refractory linings (linings from furnaces, and reactors, etc)

-
- descaling waste (scrapping out vessels)
 - coal ash from coal combustion.

Since these materials are disposed of on-site, they need to be reported to the NPI. The potential for emission of NPI substances occurs under the following circumstances:

- leachate is emitted into the ground and/or groundwater
- runoff from the site is emitted into a water body
- fugitive air emissions are emitted into the atmosphere.

An indication of the possible NPI emissions and associated sources are provided in Table 5.

2.1.7 Maintenance and support functions

Maintenance and support functions are unlikely to trip the reporting of NPI substances because of the quantities of materials handled. However, emissions from these sources, if significant, may need to be reported because other activities at the facility trip thresholds.

3 Emission sources

General information regarding emission sources can be located in *The NPI Guide*.

3.1 Emissions to air

Air emissions may be categorised as fugitive emissions or point-source emissions.

3.1.1 Fugitive emissions

These are emissions not released through a vent or stack. Examples of fugitive emissions from the alumina refining process include emissions from vehicles, dust from stockpiles, volatilisation of vapour from vats and open vessels, or spills resulting from materials handling and storage. Emissions emanating from ridgeline roof-vents, louvers, and open doors of a building as well as equipment leaks, such as from valves and flanges are also examples of fugitive emissions. Emission factor EETs are the usual method for determining losses from fugitive emission sources.

3.1.1.1 Emissions from materials handling and storage

In the specific context of alumina refining, no EETs are currently available to quantify emissions from these operations. However, many of the materials handling and storage activities conducted at alumina refineries are similar to those found at mine sites (refer to the Emission estimation technique manual for mining for further details and emission factors).

3.1.1.2 Process sources

Emission estimation techniques for grinding, precipitation, digestion, drying and calcining will vary depending on the type of data available. If source testing is performed for other compliance programs, then the results can be used for emissions estimation.

You should note that in addition to the EETs discussed in this section, emissions can be estimated using other methodologies provided in this manual such as mass balance and/or monitoring data (Section 5).

The default method for estimating emissions of fugitive dust from exposed tailing storage facilities is given in USEPA AP-42. An alternative method encompassing dust monitoring and back-calculation using Gaussian equations can be used. The exact methodology may not be applicable to all refineries. Each refinery is required to obtain approval for an alternative method on a site-by-site basis via the relevant state or territory environmental agency.

An alternative to direct measurement or mass balance is the use of emission factors. You should note that in addition to NPI-listed substances presented in this section, other NPI-listed substances may also be emitted.

Emission factors for alumina refining are provided in Appendix B.

There is limited information available on emissions of volatile organic compounds (VOCs) from process operations. Section 3.1.1.3 of this Manual discusses VOC emissions further, and provides additional information regarding the speciation of VOC emissions.

The emission factors in Appendix B are available for both uncontrolled and controlled emissions.

Where available, it is preferable to use the actual pollutant reduction efficiencies of control technologies rather than the defaults provided. ‘Actual’ control efficiency data can be combined with an ‘uncontrolled’ emission estimate using Equation 1, as shown in Example 1.

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

Equation 1

$$E_{kpy,i} = (A \times OpHrs) \times EF_i \times [1 - (CE_i \div 100)]$$

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 for pollutant i, kg/t
- CE_i = overall control efficiency of pollutant i, %

This equation can be applied when uncontrolled emissions and the control efficiency associated with the particular control equipment utilised are known.

Example 1 Emissions of PM₁₀ from a wet scrubber with a control efficiency of 90 wt%

The ‘uncontrolled’ emission estimate for PM₁₀ from calcining is 5 000 000 kilograms per year. A wet scrubber, with a known control efficiency of 90 percent (by weight), is used to aid in controlling emissions. Therefore, using Equation 1, the ‘controlled’ emission estimate is:

$$\begin{aligned} \text{Controlled emission} &= 5\,000\,000 \times [1 - (90 \div 100)] \\ &= 5\,000\,000 \times 0.1 \\ &= 500\,000 \text{ kilograms per year} \end{aligned}$$

Thus, the particulate emission after considering the particulate emission control is 500 000 kilograms per year.

3.1.1.3 Volatile organic compound (VOC) emissions

3.1.1.3.1 Total volatile organic compounds (TVOCs) emissions

Very little data is available to estimate TVOCs emissions from alumina refining operations. Currently, emissions can only be estimated using source test data collected at refining facilities, if such data is available. TVOCs emission estimates can then be speciated using the methodologies outlined in the following section.

3.1.1.3.2 VOC speciation

Methodologies available for the sampling and analysis of VOCs are:

1. USEPA SW-846 method NO.0030 “Volatile Organic Sampling Train (VOST)”

-
- USEPA method No.T015 “Determination of Volatile Organic Compounds (VOCs) in air collected in specially-prepared canister and analysed by Gas Chromatography/Mass Spectrometry.” (‘Summa’ canisters)

The method used will depend on the type of measurement and the laboratory available.

Once TVOC emissions have been estimated, these emissions can be speciated into NPI-listed substances using either:

- process stream composition data; and/or
- available speciation data (in the form of weight fractions) from the USEPA.

The first methodology is likely to give more accurate estimates than those derived by using generic weight fractions developed by the USEPA. The speciation data from USEPA is limited and, therefore, a combination of these two methodologies may be required.

Each of these VOC speciation methods will be discussed in greater detail in the following sections.

3.1.1.3.2.1 Speciation based on process stream composition

This methodology involves using the compositional data for each process stream (i.e. obtained from analytical procedure such as GC/MS), and applying this data to approximate the vapour phase composition.

This EET relies on the following equation to speciate emissions from a single source:

Equation 2

$$E_i = E_{VOC} \times (WP_i \div WP_{VOC})$$

Where:

- E_i = mass emissions of NPI substance "i" (kg/hr)
 E_{VOC} = total VOC mass emission rate from a source (fugitive or stack)
 WP_i = concentration of NPI substance “i” in weight per cent
 WP_{VOC} = VOC concentration in weight per cent.

3.1.1.3.2.2 Speciation using developed weight fraction data

In the absence of analytical data, the default VOC speciation data presented in Table 1 can be used to characterise emissions of NPI-listed substances. As previously mentioned, only limited VOC speciation data has been found in the literature. Applying this speciation data requires the use of Equation 3.

Equation 3

$$E_i = E_{VOC} \times (WP_i \div 100)$$

Where:

- E_i = mass emissions of NPI substance “i” from the source (kg/hr)
 E_{VOC} = total VOC mass emission rate (kg/hr)

WP_i = weight per cent of the relevant compound in the VOC emission (as provided in Table 1).

Table 1: Speciation of VOCs which are NPI substances¹

Substance	Molecular weight (g/mol)	Weight per cent (% w/w)
Benzene	78.11	9.1
Cyclohexane	84.16	2.3
Formaldehyde	30.03	18.2
Toluene	92.13	4.5
Notes:		
1. Reference: USEPA (1990) A much greater range of substances was in the reference and the weight fractions summed to 100%. The substances above are the NPI substances.		

The degree of speciation that can be performed using this method is limited, and it is possible that other compounds present on the NPI substance list will be identified in the VOCs emitted.

3.1.1.4 Materials storage

3.1.1.4.1 Acid storage

Emissions from the storage of acids can be estimated by assuming that the vapour space within the storage tank is saturated, and at atmospheric pressure. Using the following table, and assuming ideal gas properties, an estimate can be derived.

Table 2 Acid Properties¹

Acid	Partial pressure (kPa)	Volume per cent
Sulfuric Acid ²	2.77×10^{-6}	2.73×10^{-6}
Hydrochloric Acid ³	1.41	1.4
Notes:		
1. Reference: Perry & Green (1997). Based on 1 atm and 20 °C		
2. Note that Table 2-14 on page 2-82 of Perry & Green (1997) provides an extensive table specifying the properties of sulfuric acid at various storage temperatures and solution concentrations. The term 'Vol%' above (and in the equation below) is derived by dividing the partial pressure taken from this table, by the ambient pressure of 101.3 kPa (note that the pressure data as read from the table in Perry's is in units of 'bars').		
3. Concentration = 30%. Similarly to footnote b, Table 2-10 on page 2-76 in Perry & Green (1997) provides relevant hydrochloric acid properties.		

To estimate emissions during filling operations to acid storage tanks, the following formula can be used (based on the ideal gas law):

Equation 4

$$E = 0.042 \times MW \times V_{VS} \times (\text{Vol\%/100})$$

Where:

E = mass of acid emitted during filling (kg)
 MW = molecular weight of acid (for Hydrochloric Acid = 36.5 kg/kmol; sulfuric acid = 98 kg/kmol)

V_{vs} = volume of the vapour space in the tank = volume of acid added (m^3).
 $Vol\%$ = volume per cent

3.1.1.4.2 Organic liquids storage

EETs for the storage of organic liquids (e.g. fuels) can be found in the *Emission Estimation Technique Manual for Fuel and Organic Liquid Storage*.

3.1.1.5 Trace element speciation

Metals can be speciated based on trace analysis data, or MSDS information provided by the vendor. This data can be combined with particulate emissions data (i.e. collected as source test results and/or calculated by other estimation techniques) using the equation below:

Equation 5

$$E_{kpy,i} = m \times c_i$$

Where:

$$\begin{aligned} E_{kpy,i} &= \text{mass emission of component } i \text{ (kg/yr)} \\ m &= \text{mass emission rate of particulate (kg/yr)} \\ c_i &= \text{mass fraction of component } i \text{ (mg/kg} \times 10^{-6}) \end{aligned}$$

You should note that this methodology is most applicable to emissions from low temperature sources, such as stockpiles. This is because the methodology is based on the intrinsic assumption that all metals are contained by the released particulate matter. While this may be a reasonable assumption for metals with very low vapour pressures, more volatile metals such as mercury are likely to be partially present in vapour form at increased temperatures. However, insufficient information is currently available to produce better estimates than those derived by source testing.

In addition, metals can be speciated in bauxite and red mud using data presented in the literature, as provided in Table 3. These data can be combined with particulate emission data using the equation provided above. The information in Table 3 is a guide only. If the relevant information is not available for your facility use the maximum values provided in Table 3.

Table 3 Speciation data for alumina refining ^{1, 2, and 3}

NPI substance	Bauxite (mg/kg)	Red mud (mg/kg)
Antimony and compounds	0.1 – 0.5	0.1 – 1.4
Arsenic and compounds	4.0 – 15.9	4.9 – 45.8
Beryllium and compounds	0.1 – 0.3	0.2– 0.6
Boron and compounds	0.1 - 20.0	0.3 - 20.0
Cadmium and compounds	0.0 – 0.1	0.0 – 0.1
Chromium (III) compounds	26.0 – 337.0	40.0 – 628.0
Cobalt and compounds	0.3 – 2.4	1.5 – 6.1
Copper and compounds	1.5 – 37.0	2.2 –64.0
Fluoride compounds	5.0 – 600.0	270.0 – 462.5
Lead and compounds	4.7 – 26.6	10.2 – 61.9
Manganese and compounds	7.6 – 136.0	25.0 – 221.9
Mercury and compounds	0.0 – 0.9	0.0 – 0.5
Nickel and compounds	1.6 – 4.4	4.5 – 18.0
Selenium and compounds	0.1 – 2.3	0.1 – 5.0
Zinc and compounds	1.3 – 20.2	6.8 .– 37.4

Notes:

1. Reference: Australian Aluminium Council
2. A large refinery can generate more than 3.5 Mt of alumina per annum
3. If you are not aware of the speciation data from your facility use the data above. If a range is provided use the higher value.
4. Figures for speciation may not represent all bauxite. It is acknowledged that the mineralogy and processing efficiencies vary from site to site.

3.1.2 Point source emissions

Point source emissions are directed into a vent or stack and emitted through a single point source into the atmosphere.

It is expected that in alumina refining, fuel will be combusted in a boiler. For determining emissions from burning fuel, refer to the NPI *Combustion in Boilers* manual.

Air emission control technologies, such as electrostatic precipitators (ESPs), fabric filters or baghouses, and wet scrubbers, are commonly installed to reduce the concentration of particulates in processing off-gases before emission through a stack. The collection efficiency of the abatement equipment needs to be considered where such equipment has been installed, and where emission factors from uncontrolled sources have been used in emission estimations.

3.1.2.1 Emissions of sulfur dioxide using mass balance

The preferred estimation technique for sulfur dioxide (SO₂) is as follows. Estimates of SO₂ emissions can be made using the following equation, which assumes 100% conversion of sulfur to SO₂:

Equation 6

$$\text{Emission of SO}_2 \text{ (kg/hr)} = \text{fuel usage (kg/hr)} \times (\text{wt}\%S/100) \times 2$$

Where:

- Fuel usage = the feed rate of fuel (i.e. oil or gas) to the combustion system in kg/hr
- wt% S = the weight per cent of sulfur (as elemental S) in the fuel

3.2 Emissions to water

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

- surface waters (lakes, rivers, dams, estuaries)
- coastal or marine waters, and
- stormwater runoff.

Emissions of toxic substances to waterways may pose environmental hazards. Most facilities emitting NPI-listed substances are required by their state or territory environment agency to closely monitor and measure these emissions. Existing sampling data can be used to calculate annual emissions to the NPI.

If no wastewater monitoring data exists, emissions to process water can be calculated based on a mass balance or using emission factors.

Discharge of listed substances to a sewer or tailings dam is not regarded as an emission, and is therefore not reportable as such to the NPI. However, reporting as a transfer will be required if NPI thresholds are exceeded.

Example 1 and Example 2 show how emissions can be estimated from point source discharges. The first example is relevant for wastewater streams that have a relatively constant daily flow rate, and the measured concentration of the relevant NPI substance in the stream does not vary greatly. The second example is applicable for streams that have more variable flow rates and composition (e.g. stormwater).

Example 2 NPI emissions from a wastewater stream

The facility has exceeded the Category 2b threshold and has a requirement to report on various substances, for example, cadmium. The following information is known regarding the wastewater stream:

- the wastewater stream contains an average cadmium concentration of 500 mg/L
- the stream is sent to an on-site wastewater treatment plant at a rate of 5 L/minute
- the stream leaving the plant contains 25 mg/L of cadmium (and is discharged to a local water body)
- the plant operates 24 hours per day for 330 days per year

Using the data above, determine the quantity of cadmium released from the wastewater treatment plant.

STEP 1: Determine the annual quantity of wastewater discharged

$$\begin{aligned} \text{Volume} &= (5 \text{ L/min}) \times (60 \text{ min/hour}) \times (24 \text{ hour/day}) \times (330 \text{ days/year}) \\ &= 2\,376\,000 \text{ L/year} \end{aligned}$$

STEP 2: Determine the quantity of cadmium exiting the plant

$$\begin{aligned} \text{Quantity (OUT)} &= (2\,376\,000 \text{ L/year}) \times (25 \text{ mg/L}) \\ &= 59\,400\,000 \text{ mg/year} \end{aligned}$$

= 59 400 g/year
 = 59.4 kg/year

Therefore, based on the calculations above, 59.4 kg/year of cadmium and compounds is discharged from the plant annually, and is required to be reported under the NPI since it is being emitted to the environment.

Table 4 Measurement data

Measured flow (1 × 10 ⁶ litres/day)	Cadmium (µg/L)	Daily release (kg)
1.660	918	1.52
1.576	700	1.10
1.668	815	1.36
1.760	683	1.20
1.456	787	1.15
1.360	840	1.14
1.828	865	1.58
1.696	643	1.09
1.852	958	1.77
1.656	681	1.13
1.904	680	1.29
1.724	628	1.08
1.476	807	1.19
1.568	729	1.14
1.292	964	1.25
1.208	722	0.87
1.432	566	0.81
1.288	510	0.66
1.320	630	0.83
1.288	630	0.81
1.632	652	1.06
1.768	649	1.15
1.424	695	0.99
1.560	758	1.18
1.692	658	1.11
1.948	970	1.89
	Average	1.17 kg/day

Example 3 Cadmium and compounds emissions to water based on regular monitoring of wastewater from a facility

This example is a little more complex than the previous one because it requires the analysis of all monitoring data collated in a year from which an average can be derived. In this example, samples are taken fortnightly to measure the discharge flow from a facility, as well as the cadmium levels in the discharge water. The data collected over a single year is presented in Table 4.

The daily release is derived by multiplying the daily flow rate by the measured level of cadmium. The annual release can be determined by multiplying the average daily release shown in Table 4, by the number of days the wastewater treatment plant discharges per year.

For this example, the plant is assumed to be operational for 300 days per year.

Therefore, the annual emission estimate is derived as follows:

Annual emission of cadmium and compounds

$$\begin{aligned}\text{NPI emission} &= (1.17 \text{ kg/day}) \times (300 \text{ days/year}) \\ &= 351 \text{ kg/year of cadmium and compounds}\end{aligned}$$

Therefore, it is estimated that 351 kg of cadmium and compounds is emitted from the facility annually.

3.3 Emissions to land

Emissions of substances to land include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids, and such emissions may contain NPI-listed substances. Emission sources can be categorised as:

- surface impoundments of liquids and slurries, *and*
- unintentional leaks and spills.

Some facilities may use treated wastewater for irrigation. This wastewater need only be considered for NPI reporting if it contains an NPI-listed substance. For NPI purposes this is categorised as an emission to land.

To characterise emissions to land, three general EETs are discussed here:

- groundwater monitoring
- spills
- on-site disposal.

3.3.1 Groundwater monitoring

Some facilities conduct monitoring of groundwater to characterise emissions from the facility. Where available, this monitoring data can be used to assist in the characterisation of emissions. This involves determining upstream and downstream concentrations, and using this information in conjunction with groundwater flow information to determine the contribution of the facility to pollutant levels in the groundwater.

In terms of meeting NPI reporting requirements, this approach is reasonable in situations where there is no loss of substances (e.g. due to evaporation) prior to the substance entering the groundwater, and where the time between the release occurring and the substance entering the groundwater is minimal. Therefore, for those facilities where groundwater monitoring captures all emissions to land, such monitoring can be used as a reasonable measure of emissions to the environment. If this is not the case, (e.g. where the rate of transmission through the soil/clay is low, or when there are other routes where substances to land are carried off-site, such as evaporation or surface run-off) it will be necessary to characterise these emissions using the other EETs presented in this manual.

3.3.2 Spills

For many facilities the primary source of emissions to land will be because of spills, including intentional spillage due to vessel wash down. Accidental spills can contribute to emissions to land directly, to water through runoff, and to air.

Unless spilled material is routed to a secure containment facility, the quantity of material spilled, less any material that is collected, must be reported under the NPI. In practical terms, a log of spillages could be maintained detailing the quantities spilled and the composition of the spill (in particular the quantities of NPI substances spilled). This log could then provide the basic information required for NPI reporting.

You should note that if the spill is a volatile liquid, it is reasonable to assume that the entire light end fraction is volatilised and the remaining liquid is released into the ground. However, if the liquid is not volatile and no material is collected, it is reasonable to assume that all material is released to the land. The time, quantity of spill, temperature, and porosity of the soil all play an important part in the estimation of release.

The evaporation rate of compounds into the atmosphere is given by the following equation:

Equation 7

$$E_{\text{VAP}} = 1.2 \times 10^{-10} (\text{MW}(P_{\text{vap},i}) \div T) \times U^{0.78} \times X^{0.89} \times Y$$

Where:

E_{VAP}	=	evaporation rate of substance “i” (g/s)
U	=	wind speed over the surface of the spill (cm/s)
X	=	downwind dimension (cm)
Y	=	crosswind dimension (cm)
MW	=	molecular weight of substance “i” (can be obtained from Perry & Green (1997) or other standard chemical engineering reference texts)
$P_{\text{vap},i}$	=	vapour pressure of substance “i” at spill temperature T (dyne/cm ² = 0.0001 kPa)
T	=	temperature (K)

Once losses to the atmosphere have been quantified, emissions to land can be estimated using the following equation:

Equation 8

$$ER_{\text{LAND},i} = Q_{\text{SPILL}} - ((\text{time}) \times (E_i)) - Q_{\text{REMOVED}}$$

Where:

$ER_{\text{LAND},i}$	=	emission to the land of compound “i”
Q_{SPILL}	=	quantity of compound in the liquid spilled
Q_{REMOVED}	=	quantity of pollutant cleaned up
E_i	=	loss through evaporation of substance “i” as estimated using the evaporation equation above

Time = time period between when the liquid was initially spilled, and eventual clean up

3.3.3 On-site disposal

Facilities with provision for on-site disposal of wastes will need to consider whether the disposal is classed as a transfer, or as an emission to land under the NPI. In either case, reporting will be required under the NPI if NPI thresholds are exceeded. In a similar approach as outlined for spills, the most effective EET involves maintaining a record of all such disposal to land and, in particular, the amount of NPI substances contained in the material disposed of.

4 Threshold calculations

“Usage” of NPI substances is a determinant of whether NPI thresholds for Category 1, 1a and 1b substances have been tripped. Usage is defined as meaning the handling, manufacture, import, processing, coincidental production or other uses of the substances.

The usage of each of the substances listed as Category 1, 1a and 1b must be estimated to determine whether the Category 1 threshold (10 tonnes), Category 1a threshold (25 tonnes), or Category 1b threshold (5 kilograms) is exceeded. Once a threshold for a substance is exceeded, emissions of that substance must be reported for all operations and processes carried out at the facility, even if the actual emissions of the substances are very low or zero.

Category 2a and 2b substances are substances that are common products of combustion or other thermal processes. The NPI reporting thresholds for Category 2a are:

- burning of 400 tonnes or more fuel or waste in a year; or
- burning 1 tonne or more of fuel or waste in an hour at any time during the reporting year

The NPI thresholds for Category 2b substances are:

- burning 2 000 tonnes or more of fuel or waste in a year;
- consuming 60 000 megawatt hours or more of energy e.g. electricity in a year;
- a facility that has maximum potential power consumption of 20 megawatts or more at any time in the year.

Table 5 outlines substances for which thresholds are expected to be exceeded as a result of activities conducted at an alumina refinery:

Table 5 NPI substances

Activity	NPI substances potentially emitted	Destination		
		Air	Land	Water
Combustion	Arsenic and compounds Beryllium and compounds Cadmium and compounds Carbon monoxide Chromium (III) compounds Chromium (VI) compounds Copper and compounds Fluoride compounds Hydrochloric acid Lead and compounds Magnesium oxide fume Mercury and compounds (fume) Nickel and compounds Nickel carbonyl Nickel subsulfide Oxides of nitrogen Particulate matter (10 micrometers or less in diameter) (PM ₁₀) Particulate matter (2.5 micrometers or less in diameter) (PM _{2.5}) Polychlorinated dioxins and furans Polycyclic aromatic hydrocarbons (PAHs) Sulfur dioxide Total Volatile Organic Compounds (TVOCs)	EETs for oil and gas can be found in the <i>Combustion in Boilers Manual</i> . EETs for coal combustion presented in <i>Emission Estimation Technique Manuals for Combustion in Boilers and Fossil Fuel Electric Power Generation</i> .	Potential for leachate from ash storage (See Section 2.1.6 of this Manual).	
Aggregate handling and storage- bauxite (Section 2.1.2)	Particulate material giving rise to emissions of the following substances: <ul style="list-style-type: none"> • Arsenic and compounds • Boron and compounds • Chromium (III) compounds 	Fugitive dust (Section 3.1.1.2)	NA	Potential for diffuse runoff due to rain (Section 3.2)

Activity	NPI substances potentially emitted	Destination		
		Air	Land	Water
	<ul style="list-style-type: none"> Chromium (VI) compounds Cobalt and compounds Copper and compounds Fluoride compounds Manganese and compounds Selenium and compounds Zinc and compounds 			
Aggregate handling and storage- limestone and other aggregate (Section 2.1.2)	Particulate matter 10 micrometres or less in diameter (PM ₁₀) Particulate matter 2.5 micrometres or less in diameter (PM _{2.5})	Fugitive dust (Section 3.1.1.2)	NA	Potential for diffuse runoff due to rain (Section 3.2)
Bulk chemical storage (Section 2.1.3)	Hydrochloric acid Organics released from the handling/storage of hydrocarbons Sulfuric acid Total volatile organic compounds (TVOCs)	Storage of these substances in tanks may give rise to fugitive emissions to air (see the NPI Fuel and Organic Liquid Storage manual)	Section 3.3.2 provides a discussion on spills, and how these may be characterised	NA
Bauxite processing- grinding (Section 2.1.4)	Particulate material giving rise to emissions of the following substances: <ul style="list-style-type: none"> Arsenic and compounds Boron and compounds Chromium (III) compounds Chromium (VI) compounds Cobalt and compounds Copper and compounds Fluoride compounds Manganese and compounds Selenium and compounds Zinc and compounds 	Air emissions through mill ventilation	NA	NA
Bauxite processing- digestion (section 2.1.4)	VOCs which are NPI substances including, but not limited to: <ul style="list-style-type: none"> Acetaldehyde 	Fugitive emissions of organic volatiles (VOCs) and other compounds EETs	NA	NA

Activity	NPI substances potentially emitted	Destination		
		Air	Land	Water
	<ul style="list-style-type: none"> • Acetone • Benzene • Chloroform • Cyclohexane • Ethanol • Ethylbenzene; • Methanol • Styrene • Trichloroethane • Polycyclic aromatic hydrocarbons (PAHs) • Xylenes (all isomers) <p>Other NPI substances:</p> <ul style="list-style-type: none"> • Carbon disulfide • Hydrogen sulfide • Mercury • Sulfur dioxide 			
Bauxite processing- precipitation and clarification (Section 2.1.4.3)	<p>VOCs which are NPI substances including, but not limited to:</p> <ul style="list-style-type: none"> • Acetaldehyde • Acetone • Benzene • Chloroform • Cyclohexane • Ethanol • Ethylbenzene • Methanol • PAHs • Styrene • Trichloroethane 	Organic volatiles and other compounds released through process vents	NA	NA

Activity	NPI substances potentially emitted	Destination		
		Air	Land	Water
	<ul style="list-style-type: none"> • Xylenes (all isomers) Other NPI substances including: <ul style="list-style-type: none"> • Carbon disulfide • Hydrogen sulfide • Sulfur dioxide 			
Drying/calcining (Section 2.1.5)	<ul style="list-style-type: none"> • Carbon monoxide • Oxides of nitrogen • Polycyclic aromatic hydrocarbons (PAHs) • Particulate matter 10 micrometres or less in diameter (PM₁₀) • Sulfur dioxide • TVOCs The following substance could be contained in particulate matter: <ul style="list-style-type: none"> • Arsenic and compounds • Boron and compounds • Chromium (III) compounds • Chromium (VI) compounds • Cobalt and compounds • Copper and compounds • Fluoride compounds • Manganese and compounds • Selenium and compounds • Zinc and compounds 	Stack emissions from the kiln	NA	NA
Spent process material storage- red mud from alumina processing (Section 2.1.6)	Particulate matter giving rise to emissions of the following substances: <ul style="list-style-type: none"> • Arsenic and compounds • Boron and compounds • Chromium (III) compounds • Chromium (VI) compounds 	Fugitive emissions from the surface (storage) as well as handling (Section 3.1.1)	Leachate (See Section 2.1.6 of this Manual).	Surface runoff

Activity	NPI substances potentially emitted	Destination		
		Air	Land	Water
	<ul style="list-style-type: none"> • Cobalt and compounds • Copper and compounds • Fluoride compounds • Manganese and compounds • Selenium and compounds • Zinc and compounds Organics (see precipitation)			
Spent process material storage-refractory waste (Section 2.1.6)	Chromium (III) compounds and Chromium (VI) compounds	Refractory waste	Refractory waste	Refractory waste
Spent process material storage-descaling waste (Section 2.1.6)	See above (red mud)	Descaling waste	Descaling waste	Descaling waste
Spent process material storage- coal ash (Section 2.1.6)	Organics Metals and compounds as per red mud	Coal ash	Coal ash	Coal ash

5 Techniques for estimating emissions

The emissions to air, land and water for every NPI substance that trips a threshold must be reported from all point and fugitive sources on the facility. *The NPI Guide* outlines detailed information on thresholds and identifying emission sources.

There are five types of emission estimation techniques (EETs) that may be used to calculate emissions from your facility. These are:

- sampling data or direct measurement
- mass balance
- fuel analysis or engineering calculations
- emission factors, and,
- an approved alternative.

Generally, alumina refining activities report emissions using emission factor, direct measurement and mass balance methods. These methods are described in this section, but the other emission estimation techniques can be found in *The NPI Guide*.

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 manual, your data will also be displayed as being of acceptable reliability.

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 immediately (within 24 hours) during clean up operations.

5.1 Direct measurement

You may wish to use direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements.

Monitoring data can be expressed in a range of units. The following discussion may be of assistance when converting monitoring results into annual emission estimates for the purposes of the NPI. It is important to remember that the calculation of annual emissions must also take into account the number of hours per year the source is discharging to the environment.

Stack data is commonly presented in terms of either actual flow, or a ‘normalised’ flow. The difference is that normalised data is standardised to a particular temperature and pressure, typically 0°C and 1 atm respectively. However, sometimes it may be referenced to 25°C and 1 atm. The following terms may be used when presenting data:

- acm – actual cubic metre (at actual temperature and pressure);
- scm – standard cubic metre (typically at 25°C and 1 atm, although sometimes it may be at 20°C, or even 0°C); and
- Nm³ – normal cubic metre (typically at 0°C and 1 atm).

It is essential to know the conditions under which the source test data is collected before determining annual emission estimates. You should note that the measured concentrations and flue gas flows are usually presented on source test reports at the same conditions (i.e. temperature and pressure).

Provided below are two examples of the use of sampling data to characterise annual emissions. Example 4 is where the concentration of the compound is presented at the same conditions as the measured flow rate. Example 5 is where the concentration and flue gas flows are measured under different conditions.

Example 4 Emissions determined by direct measurement: emission factor units are the same as the process flow units

The following example relates to a situation where the concentration of cadmium and compounds is presented at the same conditions as the measured flow rate.

The following data is known:

- the flue gas flow from a stack is measured at 30 Nm³/sec
- the measured concentration of cadmium in the flue gas is 0.01 mg/Nm³
- the stack operates 24 hours per day for 300 days per year

First of all, the number of seconds per year the stack is emitting is determined:

$$\begin{aligned} \text{No. seconds/year} &= (3\,600 \text{ sec/hour}) \times (24 \text{ hours/day}) \times (300 \text{ days/year}) \\ &= 2.6 \times 10^7 \text{ seconds/year} \end{aligned}$$

Using this data, the emission is derived as follows:

$$\begin{aligned} \text{Emission} &= (30 \text{ Nm}^3/\text{sec}) \times (0.01 \text{ mg/Nm}^3) \times (2.6 \times 10^7 \text{ sec/year}) \\ &= 7.8 \text{ kg of cadmium and compounds per year} \end{aligned}$$

Example 5 Emissions determined by direct measurement: emission factor units are different from the process flow units

If the concentration and flue gas flows are measured under different conditions then additional calculations are required. For this example, the following data is known:

- the flue gas flow from a stack is measured at 100 acm/sec
- the flue gas flow from a stack is measured at 100 acm/sec
- the stack operates 24 hours per day for 300 days per year
- the conditions at the stack tip are approximately 150 °C and 1 atm

Using the actual stack data, the ‘actual’ flue gas flow can be converted to a normalised flow using a ratio of temperatures. You should note that the temperatures must be presented using the absolute temperature scale of Kelvin (i.e. 0 °C = 273 K). The conversion is then performed as follows (noting that the actual stack conditions are 150 + 273 = 423 K):

$$\begin{aligned} \text{Flue gas (Nm}^3\text{/sec)} &= 100 \text{ acm/sec} \times (273 \div 423) \\ &= 64.5 \text{ Nm}^3\text{/sec} \end{aligned}$$

The emission rate is then derived using the same methodology as outlined previously

$$\begin{aligned} \text{Emission} &= (0.01 \text{ mg/Nm}^3) \times (64.5 \text{ Nm}^3\text{/sec}) \times (2.6 \times 10^7 \text{ sec/year}) \\ &= 16.8 \text{ kg of cadmium and compounds per year} \end{aligned}$$

5.2 Emission factors

An emission factor is a tool that is used to estimate emissions to the environment. In this manual, it relates to the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are usually expressed as the weight of a substance emitted multiplied by the unit weight, volume, distance or duration of the activity emitting the substance (e.g. kilograms of substance per tonne of product).

When using emission factors, you should be aware of the associated emission factor rating (EFR) code and what the rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. 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:

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

(listed previously as Equation 1)

$$E_{kpy,i} = (A \times \text{OpHrs}) \times EF_i \times [1 - (CE_i \div 100)]$$

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 for pollutant i, kg/t
CE_i	=	overall control efficiency of pollutant i, %

Emission factors applicable to this manual are listed in Appendix B. You must ensure that you estimate emissions for all substances relevant to your process.

Emission factors developed from measurements for a specific process may sometimes be used to estimate emissions at other sites. For example, a company may have several units of similar model and size, if emissions were measured from one facility, an emission factor could be developed and applied to similar sources. If you wish to use a site-specific emission factor, you should first seek approval from your state or territory environment agency before its use for estimating NPI emissions.

5.3 Mass balance

Mass balances involve examining a process to determine whether emissions can be characterised based on an analysis of operating parameters, material composition, and total material usage. Mass balance involves the quantification of total materials into and out of a process with the difference between inputs and outputs being accounted for as an emission to the environment (to air, water, land), or as part of the facility's waste. Mass balance is particularly useful when the input and output streams can be readily characterised, and this is most often the case for small processes and operations.

Mass balances can be undertaken for a whole facility or the individual process steps that make up the facility.

Information about mass balances in relation to the NPI is in the NPI Guide.

5.4 Approved alternative

You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your state or territory environmental agency. For example, if your company has developed site-specific emission factors, you may use these if they have been approved by your local environmental agency.

6 Transfers of NPI substances in waste

The NPI requires the mandatory reporting of NPI substances that are transferred as waste to a final destination. Transfers are required to be reported if a Category 1, Category 1a, Category 1b or Category 3 reporting threshold is exceeded. For example, if the threshold has been exceeded for the category 1 substance sulfuric acid as a result of use of this substance on site, transfers to final destination of sulfuric acid as well as emissions are reportable.

There is no requirement to report transfers of substances that are exclusively Category 2a or 2b in the event that they have been tripped only by the fuel and energy use threshold (i.e. there is no requirement to report transfers of oxides of nitrogen, particulate matter $\leq 10 \mu\text{m}$, particulate matter $\leq 2.5 \mu\text{m}$, polychlorinated dioxins and furans, or polycyclic aromatic hydrocarbons).

Both emissions and transfers are reportable in kilograms.

In the specific context of alumina refining, the quantities of NPI substances contained in waste moved onsite or offsite to landfill or other final destination will need to be reported as a transfer. For example, NPI substances in bauxite residue (red mud), such as arsenic, cadmium, boron and fluoride, would be reportable as transfers. Transfers are also reportable where waste containing NPI substances is discharged to the sewerage system as part of an industrial disposal system.

Currently there are no generic transfer factors that are available for estimation of transfers from alumina refining operations. Reporters are advised to estimate transfers based on monitoring, licensing arrangements (such as those for discharge to sewer), engineering calculations, or an appropriate alternative technique for the operation.

The transfer of NPI substances to a destination for reuse, recycling, reprocessing, purification, partial purification, immobilisation, remediation or energy recovery can be reported voluntarily. This is an opportune way for facilities to promote good news stories to their local community.

Further information regarding transfers of waste can be located in *The NPI Guide*.

7 Next steps for reporting

This manual has been written to reflect the common processes employed in alumina refining. To ensure a complete report of the emissions for your facility, it may be necessary to refer to other EET manuals. These include:

- Combustion in boilers
- Combustion in engines
- Fuel and organic liquid storage
- Fugitive emissions, *and*
- Mining.

When you have a complete report of substance emissions from your facility, report these emissions according to the instructions in *The NPI Guide*.

8 References

AWMA (1992) *Air Pollution Engineering Manual*, Air & Waste Management Association, Van Nostrand Reinhold, 1992.

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USEPA (1997b) *Factor Information Retrieval System (FIRE)*, Office of Air Quality Planning and Standards, US EPA, Research Triangle Park, (AirChief CD-ROM, 1997, Version 5.0)

USEPA (1998a), *Fuel Oil Combustion*, March 1998 Revision to AP-42 Section 1.3.

USEPA (1998b), *Natural Gas Combustion*, September 1998 Revision to AP-42 Section 1.4

The following Emission Estimation Technique Manuals referred to in this Manual can be obtained from the web (www.npi.gov.au)

- Emission estimation technique manual for combustion in boilers;
- Emission estimation technique manual for fuel and organic liquid storage;
- Emission estimation technique manual for mining;
- Emission estimation technique manual for fossil fuel electric power generation; and
- Emission estimation technique manual for sewage and wastewater treatment.

Appendix A: Abbreviations and definitions

Term	Definition
Acm	actual cubic metre (at actual temperature and pressure)
Atm	atmospheric pressure, equivalent to 760 mm Hg or 101.35 kPa
CO	carbon monoxide
EET	Emission Estimation Technique
ESP	electrostatic precipitator
g/mol	grams per mole
kg	kilograms
kmol	kilomoles = 1000 moles
L	litres
LPG	liquefied petroleum gas
µg	micrograms = 0.000001 g = 1×10^{-6} g
µg/L	micrograms per litre
mg	milligrams = 0.001 g = 1×10^{-3} g
mg/L	milligrams per litre
moles	unit that measures an amount of substance
Mt	megatonnes = 1,000,000 tonnes
Nm ³	normal cubic metre, volume of a gas at normal pressure and temperature, 1 atm, 0 °C
NPI	National Pollutant Inventory
NO _x	oxides of nitrogen
PAHs	polycyclic aromatic hydrocarbons
PM ₁₀	particulate matter 10 micrometres or less in diameter
PM _{2.5}	particulate matter 2.5 micrometres or less in diameter
Scm	Standard cubic metre (typically 25 °C and 1 atm, although it may sometimes be 20 °C or 0 °C)
SO ₂	sulfur dioxide
TVOCs	total volatile organic compounds
VOCs	volatile organic compounds

Appendix B: Emission factors

Emission factors for alumina refining processes ¹

Operation	Total particulate ^{4,5} (kg/tonne)
Bauxite grinding ²	
Uncontrolled	3
Spray tower	0.9
Floating bed scrubber	0.85
Quench tower and spray screen	0.5
Aluminium hydroxide calcining	
Uncontrolled ³	100
Spray tower	30
Floating bed scrubber	28
Quench tower	17
ESP	2
Notes:	
<ol style="list-style-type: none"> 1. Reference: USEPA, (1997a). For bauxite grinding, factors expressed as kg/tonne bauxite processed. For aluminium calcining, factors expressed as kg/tonne of alumina produced. 2. Note that many Australian alumina refineries use wet milling. In this situation, the dust emissions are expected to be zero. 3. After multicyclones. 4. The data available in the literature pertains to total particulate rather than the NPI-listed PM₁₀. In the absence of better data, the total particulate data can be used to provide conservative upper bounds for PM₁₀ emissions. 5. With regards to emission controls for PM₁₀, 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. 	

Appendix C: Process description

Metallic mineral processing typically involves the mining of ore from either open pit or underground mines, the crushing and grinding of ore, the separation of valuable minerals from matrix rock through various concentration steps and, at some operations, drying, calcining, or pelletizing of concentrates to assist further handling and refining.

The number of crushing steps necessary to reduce ore to the proper size varies with the type of ore. Softer ores, such as some uranium, bauxite, and titanium/zirconium ores, require little or no crushing. Final comminution of both hard and soft ores is often accomplished by grinding operations using media such as balls or rods of various materials. Grinding is most often performed with ore/water slurry, which reduces particulate matter (PM) emissions to negligible levels.

After final size reduction, beneficiation of the ore increases the concentration of valuable minerals by separating them from the matrix rock. Various physical and chemical processes are used to concentrate the mineral. Most often, physical or chemical separation is performed in an aqueous environment that eliminates PM emissions, although some ferrous and titaniferous minerals are separated by magnetic or electrostatic methods in a dry environment. The concentrated mineral products may be dried to remove surface moisture.

Alumina is produced from bauxite by the Bayer Process. In the Bayer Process, aluminium hydroxides or hydrates are selectively separated from other components by extracting them with sodium hydroxide to form sodium aluminate. Alumina is then precipitated from the sodium aluminate solution, washed, and calcined. The process is shown in Section 2.

To prepare bauxite for processing, mined ore is crushed and ground in ball mills to a finely divided state. Most bauxite as mined has a low moisture content. If the moisture content is high, then the bauxite must be dried in rotary kilns before it is sent to storage. The drying operation emits significant amounts of bauxite dust.

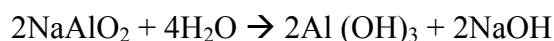
To produce high purity alumina suitable for aluminium reductions cells, finely divided bauxite containing 30-70% alumina is slurried with sodium hydroxide solution and reacted at high temperature and pressure in reactors called digesters. Sodium aluminate is formed leaving behind most of the silicon, iron, titanium, and calcium oxides as insoluble components in the solid waste residue. This is formed according to the following general equation:



The hot slurry is usually cooled by flash evaporation, producing steam that is used to heat incoming slurry. Next, the slurry is processed in a series of clarification steps designed not only to separate the solid residue from the liquor, but also to rid the solution of the impurities that would lower the quality of the aluminium when the alumina later is electrolysed. These impurities are mainly oxides of silicon and iron.

If the bauxite contains coarse material (mainly sand), it is first removed from the slurry in hydrocyclones, and starch or some settling agent is added to the overflow

before it enters a clarifier. Starch promotes agglomeration and settling of the fine particles, and the relatively clear overflow from the clarifier is filtered in either filter presses, or sand filters to remove any remaining suspended solids. The clarifier underflow is then washed in thickeners to remove as much caustic as possible before it is pumped to a bauxite residue pond. The filtrate containing sodium aluminate, now at 50 °C to 70 °C, is processed in precipitators where aluminium hydroxide crystallises and precipitates as shown in the following:



After precipitation, the slurry containing trihydrate crystals is sent to classification, where the product is separated according to crystal sizes. The coarse product is washed to remove excess sodium hydroxide, dewatered on vacuum filters, and sent to calcination. The finer crystals are recycled to the precipitation process as seed, thereby providing nucleation sites for precipitation to occur. Spent liquor from the precipitators is recycled to the digesters.

The coarse alumina is calcined in rotary kilns or fluid-bed calciners at about 982 °C (1800 °F). During calcination, water (mechanically and chemically bound) is driven off. Calcination produces hot flue gases containing alumina and water vapour, and the usual types of control equipment consist of cyclonic separators followed by ESPs. The control equipment not only minimises air pollution, but recovers valuable product as well. Calcined alumina is stored for shipment to the smelter as feedstock for the aluminium electrolytic cells.

Appendix D: Modifications to the alumina refining emission estimation technique (EET) manual (Version 1.1 October 2007)

Page	Outline of alteration
Overall	Corrected several spelling errors. Removed parts more comprehensively covered in other NPI manuals. Directed users to the NPI Guide and relevant NPI manuals for information that is best covered in these documents. Updated, and where necessary provided captions for tables and examples to make it clear what these items are how they are to be used.
Section 1 and 2	Replaced Figures 1 to 6 with a single improved process flow diagram, Figure 1.
Section 3	Emissions to land: groundwater monitoring, spills and on-site disposal included in this section
Section 4	Elements of section 4 were condensed. Provided an outline of this section to assist users to find relevant information. Tables 2-11 condensed
Section 5	General descriptions of the emission estimation techniques given. The section on 'Monitoring' was combined with the "Mass Balance" section.
	Section on 'Assumptions and Discussion' was removed as it referred to emissions from sources now not included in the manual.
Appendix A	An 'Abbreviations and definitions' section was added to the manual.