



National Pollutant Inventory

# **Emission Estimation Technique Manual**

**for**

## **Hot Mix Asphalt Manufacturing**

*First published in June 1999*

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**EMISSION ESTIMATION TECHNIQUES  
FOR  
HOT MIX ASPHALT MANUFACTURING**

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# HOT MIX ASPHALT MANUFACTURING

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## 1.0 Introduction

The purpose of all emission estimation techniques (EET) manuals in this series is to assist Australian manufacturing, industrial, and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in hot mix asphalt manufacturing.

The asphalt manufacturing activities covered by this Manual include facilities primarily engaged in the mixing of bitumen and aggregate products into asphalt.

EET MANUAL: Hot Mix Asphalt Manufacturing

HANDBOOK: Hot Mix Asphalt Manufacturing

ANZSIC CODE: 4121 and 2520 and all codes in the 252 ANZSIC code group.

This Manual was drafted by the NPI Unit of the Queensland Department of Environment and Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key stakeholders.

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## 2.0 Process Description

This section describes the materials and equipment used and the processes employed and emissions of NPI-listed substances generated within hot mix asphalt plants. The section is designed to provide a general understanding of the inter-relationship between the industrial processes and the topics described in subsequent sections of this Manual - available emission estimation techniques, examples for estimating emissions, and uncertainty analysis of the emission estimates. This section does not attempt to replicate published engineering information that is available for hot mix asphalt manufacture.

Hot mix asphalt paving materials are a mixture of graded, high quality aggregate (which may include reclaimed or recycled asphalt pavement) and liquid bitumen, which is heated and mixed in measured quantities to produce hot mix asphalt materials. Aggregate and recycled asphalt pavement, if used, constitute over 92 percent by weight of the total hot mix asphalt mixture. Aside from the relative amounts and types of aggregate and recycled asphalt pavement used, mix characteristics are determined by the amount and grade of bitumen used. Additionally, the bitumen may be blended with petroleum distillates or emulsifiers to produce cold mix asphalt, often referred to as cutback or emulsified bitumen, respectively.

The process of producing hot mix asphalt involves drying and heating the aggregate to prepare it for the bitumen coating. In the drying process, the aggregate is dried in a rotating, slightly inclined, direct-fired drum dryer. The aggregate is introduced into the higher end of the dryer. The interior of the dryer is equipped with flights that veil the aggregate through the hot exhaust as the dryer rotates. After drying, the aggregate is generally heated to temperatures ranging from 250 to 300 °C and then coated with bitumen in one of two ways. In most drum mix plants, the bitumen is introduced directly into the dryer chamber to coat the aggregate. In batch mix plants, the mixing of aggregate and asphalt takes place in a separate mixing chamber called a pug mill.

The following types of plants primarily define the variations in the hot mix asphalt manufacturing process:

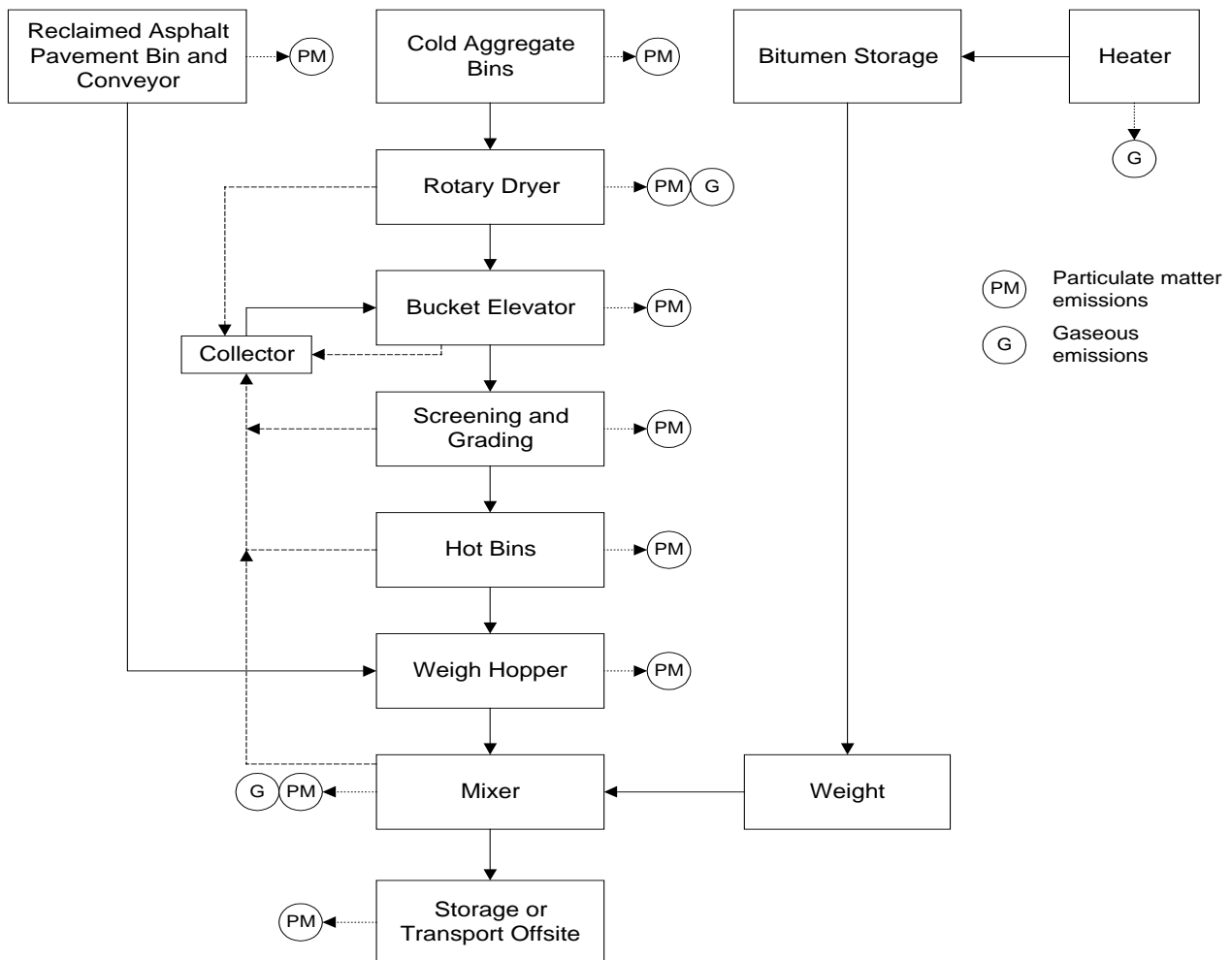
- batch mix plants;
- parallel flow drum mix plants; and
- counter flow drum mix plants.

### 2.1 Batch Mix Processing

In the batch mixing process, the aggregate is transported from storage piles and is placed in the appropriate hoppers of a cold feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a rotary dryer, which is generally gas or oil-fired.

As hot aggregate leaves the dryer, it drops into a bucket elevator and is transferred to a set of vibrating screens that drops the aggregate into individual hot bins according to size. To control aggregate size distribution in the final batch mix, the operator opens various hot bins over a weigh hopper until the desired mix and weight for individual components are obtained. Recycled asphalt pavement may also be added at this point. Concurrent with the

aggregate being weighed, liquid bitumen is pumped from a heated storage tank to an asphalt bucket, where it is weighed to achieve the desired mix. Figure 1 illustrates a schematic for a typical batch mix asphalt plant and highlights the likely emission points.



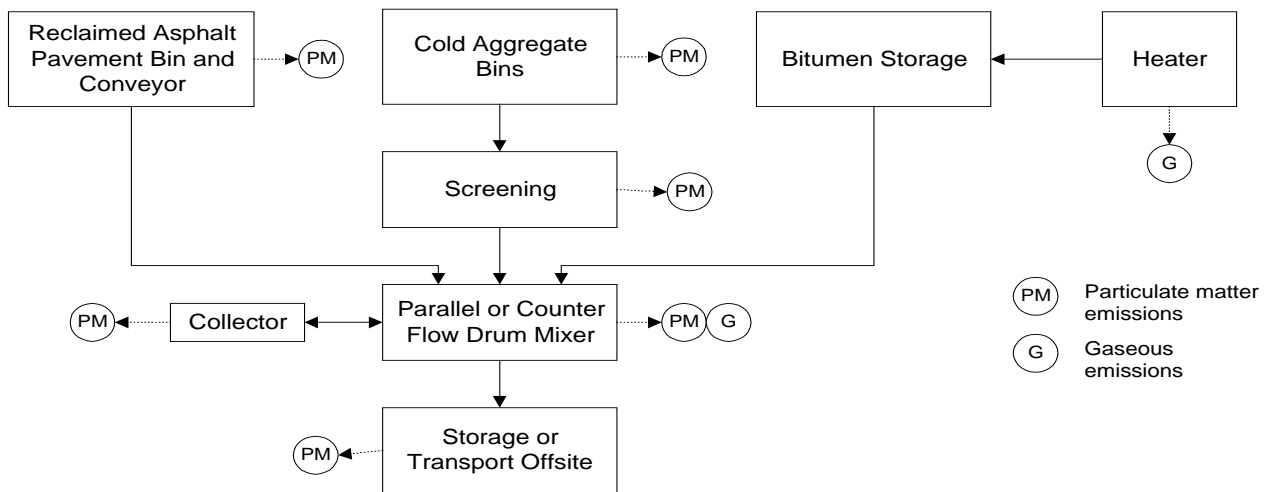
**Figure 1 - Basic Process Steps for Batch Mix Asphalt Plants**

Source: Queensland Department of Environment and Heritage, 1998.

## 2.2 Parallel Flow Drum Mixing Process

The parallel flow drum mixing process is a continuous mixing type process that uses proportioning cold feed controls for the process materials. The major difference between this process and the batch process is that the dryer is used not only to dry aggregate but also to mix the heated and dried aggregate with the liquid bitumen. Aggregate, which has been proportioned by size gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregate, as well as the combustion products, moves toward the other end of the drum in parallel. The bitumen is introduced into approximately the lower third of the drum. The aggregate is coated with bitumen as it veils to the end of the drum. The recycled bitumen pavement is introduced at some point along the length of the drum, as

far away from the combustion zone as possible (about the mid-point of the drum), but with enough drum length remaining to dry and heat the material adequately before it reaches the coating zone. Figure 2 gives a general description of a drum mix process and the emission points.



**Figure 2 - Basic Process Steps for Drum Mix Asphalt Plants**

Source: Queensland Department of Environment and Heritage, 1998.

### 2.3 Counter Flow Drum Mixing Process

In the counter flow drum mixing process, the aggregate is proportioned through a cold feed system prior to introduction to the drying process. As opposed to the parallel flow drum mixing process though, the aggregate moves opposite to the flow of the exhaust gases. After drying and heating takes place, the aggregate is transferred to a part of the drum that is not exposed to the exhaust gas and coated with bitumen. The process prevents stripping of the bitumen by the hot exhaust gas. If recycled asphalt is used, it is usually introduced into the coating chamber.

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## 3.0 Emission Sources

Emissions from hot mix asphalt plants derive from both stack (ie. ducted) and fugitive sources.

Most emissions of listed substances from bitumen plants arise from coincidental activities, such as fuel combustion. However the direct purchase and use of liquid bitumen, petroleum distillates (including kerosene and cutter oils), and emulsifiers will result in tripping the “use” threshold of total volatile organic compounds (VOCs), and some speciated VOCs, at some facilities as all of these mixtures are comprised largely of hydrocarbons.

### 3.1 Material Handling and Fugitive Emissions

Material handling includes the receipt, transport, and processing of fuel and materials used at the hot mix asphalt facility. Fugitive particulate matter (PM<sub>10</sub>) emissions from aggregate storage piles are generally caused by front-end loader operations that transport the aggregate to the cold feed unit hoppers. The amount of fugitive PM<sub>10</sub> emissions from aggregate piles will be greater in strong winds. Piles of recycled asphalt pavement, because recycled asphalt pavement is coated with bitumen, are not likely to cause significant fugitive dust emissions. Other pre-dryer fugitive emission sources include the transfer of aggregate from the cold feed unit hoppers to the dryer feed conveyor and, subsequently, to the dryer entrance. Aggregate moisture content prior to entry into the dryer is generally 3 to 7 percent. The moisture content, along with aggregate size classification, tend to minimise emissions of PM<sub>10</sub> from these sources, which contribute little to total PM<sub>10</sub> emissions.

If crushing, breaking, or grinding operations occur at the plant, these may result in fugitive PM<sub>10</sub> emissions. At all hot mix asphalt plants there may be PM<sub>10</sub> and slight process fugitive VOC emissions from the transport and handling of the hot-mix from the mixer to the storage silo and also from the load-out operations to the delivery trucks. Small amounts of VOC emissions can also result from the transfer of liquid and gaseous fuels, although natural gas is normally transported by pipeline.

### 3.2 Generator Emissions

Diesel generators may be used in portable hot mix asphalt plants to provide electricity. Maximum electricity generation during process operations is usually less than 500 kilowatts per hour (kW/hr), with rates of 20 to 50 kW per hour at other times. Emissions from these generators are likely to be uncontrolled and are correlated with fuel usage, as determined by engine size, load factor, and hours of operation. Emissions primarily include the combustion pollutants, particularly oxides of nitrogen and carbon monoxide. The *Combustion Engines EET Manual* is available for estimating emissions from these sources and is available from the addresses shown in the front of the *NPI Guide* (at the front of this Handbook.)

### 3.3 Storage Tank Emissions

Storage tanks are used to store fuel oils and heated liquid asphalts at hot mix asphalt plants, and may be a source of VOC emissions. Storage tanks at hot mix asphalt plants are

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usually fixed roof (closed or enclosed) due to the smaller size of the tanks, usually less than 100 000 litres. Emissions from fixed-roof tanks (closed or enclosed) are generally divided into two categories: working losses and breathing losses.

Working losses refer to the combined loss from filling and emptying the tank. Filling losses occur when the VOCs contained in the saturated air are displaced from a fixed-roof vessel during loading. Emptying losses occur when air drawn into the tank becomes saturated and expands, exceeding the capacity of the vapour space. Breathing losses are the expulsion of vapour from a tank through vapour expansion caused by changes in temperature and pressure. Because of the small tank sizes and fuel usage, total VOC emissions would generally be less than 700 kilograms per year. Emissions from tanks used for residual fuel oils or for bitumen may be increased when they are heated to control oil viscosity. Emissions from bitumen tanks are particularly low, due to their low vapour pressure.

The *Fuel and Organic Liquid Storage EET Manual* and the AUSTanks software program are available to assist reporting asphalt plants quantify emissions of organic liquids from tank storage.

### **3.4 Process Emissions**

The most significant source of emissions from hot mix asphalt plants is the dryer. Combustion emissions from the dryer include products of complete and incomplete combustion. Products of complete combustion include oxides of nitrogen (NO<sub>x</sub>) and, if sulfur is present in the fuel, sulfur dioxide (SO<sub>2</sub>) and other non NPI-listed substances such as carbon dioxide (CO<sub>2</sub>) and water. Products of incomplete combustion include carbon monoxide (CO), VOCs (including benzene, toluene, and xylenes), and other organic particulate matter. These incomplete combustion emissions result from improper air and fuel mixtures, such as poor mixing of fuel and air, inadequate fuel air residence time and temperature, and quenching of the burner flame. Depending on the fuel, small amounts of ash may also be emitted. In addition to combustion emissions, emissions from a dryer include water and PM<sub>10</sub> from the aggregate. Non-combustion emissions from rotary drum dryers may include small amounts of VOCs, polycyclic aromatic hydrocarbons (PAHs), NPI-listed aldehydes, and listed hazardous organics from the volatile fraction of the bitumen and organic residues that are commonly found in recycled asphalt.

For drum mix processes, the dryer contributes most of the facility's total PM<sub>10</sub> emissions. At these plants, PM<sub>10</sub> emissions from post-dryer processes are minimal due to the mixing of the bitumen.

In batch mix plants, post-dryer PM<sub>10</sub> emission sources include hot aggregate screens, hot bins, weigh hoppers, and mill mixers. Uncontrolled PM<sub>10</sub> emissions from these sources will be greater than emissions from pre-dryer sources primarily due to the lower aggregate moisture content in addition to the greater number of transfer points. Post-dryer emission sources at batch plants are usually controlled by venting to the primary dust collector (along with the dryer gas) or sometimes to a separate dust collection system. Captured emissions are mostly aggregate dust, but they may also contain gaseous VOCs and a fine aerosol of condensed liquid particles. This liquid aerosol is created by the condensation of gas into particles during the cooling of organic vapours volatilised from the asphalt

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cement and recycled asphalt pavement in the mill. The aerosol emissions are primarily dependent upon the temperatures of the materials entering the mixing process.

Recycled tyres, which are increasingly being used in Australia in the production of asphalt, may also be a source of VOC and PM<sub>10</sub> emissions. When heated, ground up tyre pieces have been shown to emit VOCs, these emissions are a function of the quantity of shredded or crumbed tyre rubber used in the liquid bitumen and the temperature of the mix.

If cutback or emulsions are used to make cold mix asphalt, VOC emissions can be significant. These emissions can occur as stack emissions from mixing of bitumen batches and as fugitive emissions from handling areas. Emission levels depend on the type and quantity of the cold mix produced. VOC emissions associated with cutback bitumen production may include naphtha, kerosene, or diesel vapours which require reporting collectively to the NPI as emissions of total VOCs.

### **3.5 Process Design and Operating Factors Influencing Emissions**

There are two methods for introducing combustion air to the dryer burners and two types of combustion chambers, with the combination resulting in four types of burner systems that can be found at hot mix asphalt plants. The type of burner system employed has a direct effect on gaseous combustion emissions, including VOCs, listed organics, CO, and NO<sub>x</sub>. The two types of burners related to the introduction of combustion air include the induced draft burner and the forced draft burner. Forced draft burners are usually more fuel efficient under proper operating and maintenance conditions and, consequently, have lower emissions. The two types of burners related to the use of combustion chambers include those with refractory-lined combustion chambers and those without combustion chambers. While most older burners had combustion chambers, today's burners by and large do not.

Incomplete combustion in the dryer burner increases emissions of CO and organics. This may be caused by:

- (1) improper air and fuel mixtures such as poor mixing prior to combustion;
- (2) inadequate residence time, and temperature that is too low; and
- (3) flame quenching.

CO and organic emissions in chamberless burners primarily results from the quenching of the flame caused by improper flighting. This occurs when the flame temperature is reduced by contact with cold surfaces or cold material dropping through the flame. Moreover, the moisture content of the aggregate in the dryer may contribute to the formation of CO and unburned fuel emissions by reducing the temperature. A secondary cause of these gaseous pollutants may be excess air entering the combustion process, particularly in the case of an induced draft burner. The use of a precombustion chamber to promote better fuel air mixing may reduce VOC and CO emissions.

NO<sub>x</sub> is primarily formed from nitrogen in the combustion air (thermal NO<sub>x</sub>) and from nitrogen in the fuel. Thermal NO<sub>x</sub> is negligible below 1300 °C and increases with combustion temperature. Fuel NO<sub>x</sub>, which is likely to be lower than thermal NO<sub>x</sub> from dryer burners, is formed by conversion of some of the nitrogen in the burner fuel. While

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residual fuel oils (Nos. 4, 5, and 6) may contain significant amounts of nitrogen, distillate oils (Nos. 1 and 2) and natural gas contain very little.

Dryer burners can be designed to operate on almost any type of fuel, including natural gas, liquefied petroleum gas (LPG), light fuel oils, and waste fuel oils. The type of fuel and its sulfur content will affect SO<sub>2</sub>, VOC, and hazardous organic emissions and, to a lesser extent, NO<sub>x</sub> and CO emissions. Sulfur in the burner fuel will convert to sulfur oxides during combustion; burner operation will have little effect on the percent of this conversion. There is negligible sulfur content in Australian natural gas and LPG; it is only added in trace amounts to give the gas a detectable odour.

VOC emissions from natural gas combustion are less than emissions from LPG or fuel oil combustion, which are lower than emissions from waste-blended fuel combustion. Ash levels and concentrations of most of the trace elements in waste oils are normally much higher than those in virgin oils, producing higher emission levels of PM<sub>10</sub> and trace metals. Chlorine in waste oils also generally exceeds levels found in virgin oils. High levels of halogenated solvents are often found in waste oil as a result of the additions of contaminant solvents to the waste oils.

When cold mix bitumen is heated, organic fumes and VOCs may be emitted as visible emissions if the asphalt is cut with lighter ends or other additives needed for a specification; however, these emissions are not normally seen when heating bitumen, as the boiling point of bitumen is much higher. In drum mix plants, hydrocarbons and PAH emissions may result from the heating and mixing of liquid bitumen inside the drum as hot exhaust gas in the drum strips light ends from the bitumen. The magnitude of these emissions is a function of the process temperatures and constituents of the bitumen being used. The mixing zone temperature in parallel flow drums is largely a function of drum length. The processing of recycled asphalt pavement materials, particularly in parallel flow plants, may also increase VOC emissions, because of an increase in mixing zone temperature during processing.

In counter flow drum mix plants, the liquid bitumen, aggregate, and recycled asphalt pavement, are mixed in a zone not in contact with the hot exhaust gas stream. Consequently, counter flow drum mix plants will likely have lower VOC emissions than parallel flow drum mix plants. In batch mix plants, the amount of hydrocarbons (ie, liquid aerosol) produced depends to a large extent on the temperature of the asphalt cement and aggregate entering the mill. PM<sub>10</sub> emissions from parallel flow drum mix plants are reduced because the aggregate and asphalt cement mix for a longer time. The amount of PM<sub>10</sub> generated within the dryer in this process is usually lower than that generated within batch dryers, but because the bitumen is heated to higher temperatures for a longer period of time, organic emissions (gaseous and liquid aerosol) are generally greater than in conventional batch plants.

## 4.0 Control Technologies

Control technologies and devices used at hot mix asphalt plants are described below and presented in Table 1. Control efficiency for a specific piece of equipment will vary depending not only on the type of equipment and quality of the maintenance and repair program at a particular facility, but also on the velocity of the air flow through the dryer.

### 4.1 Process and Process Fugitive Particulate and Metal Control

Process and process fugitive particulates at hot mix asphalt plants are generally controlled using primary and secondary collection devices. Primary devices generally include cyclone and settling chambers to remove larger particulates. Secondary devices, including fabric filters and venturi scrubbers, generally collect PM<sub>10</sub>. PM<sub>10</sub> from the dry control devices is usually collected and mixed back into the process near the entry point of the bitumen in drum-mix plants. In addition to PM<sub>10</sub> emissions, particulate control also serves to remove trace metals emitted as particulates. These controls are primarily used to reduce PM<sub>10</sub> emissions from the dryer; however at batch mix plants, these controls are also used for post-dryer sources, where fugitive emissions may be scavenged at an efficiency up to 98 percent.

#### 4.1.1 Cyclones

The cyclone is a particulate control device that uses gravity, inertia, and impaction to remove particles from a ducted stream. Large diameter cyclones are often used as primary pre-cleaners to remove the bulk of heavier particles from the flue gas before it enters a secondary or final collection system. A secondary collection device, which is more effective at removing particulates than a primary collector, is used to capture remaining PM<sub>10</sub> from the primary collector effluent.

**Table 1 - Typical Hot Mix Asphalt Plant Emission Control Technologies**

Emission Source	Pollutant	Control Technique	Typical Efficiency (%)
Process	PM <sub>10</sub>	Cyclones	50 - 75
		Multiple cyclones	90
		Settling chamber	< 50
		Baghouse	99 - 99.7
		Venturi scrubber	90 - 99.5
	VOCs	Dryer and combustion process modifications	37 - 86
	SO <sub>2</sub>	Limestone	50
Low sulfur fuel		80	
Fugitive dust	PM <sub>10</sub>	Paving maintenance	60 - 99
		Wetting & crusting agents	70 - 80
		Crushed recycled asphalt pavement material	70

Adapted from: Gunke., Kathryn O'C., 1992.

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### 4.1.2 Multiple Cyclones

A multiple cyclone consists of numerous small-diameter cyclones operating in parallel. Multiple cyclones are less expensive to install and operate than fabric filters, but are not as effective at removing smaller particulates. They are often used as pre-cleaners to remove the bulk of heavier particles from the flue gas before it enters the main control device.

### 4.1.3 Settling Chambers

Settling chambers, also referred to as knock-out boxes, are used at hot mix asphalt plants as primary dust collection equipment. To capture remaining  $PM_{10}$ , the primary collector effluent is ducted to a secondary collection device such as a baghouse, which is more effective at removing particulates.

### 4.1.4 Baghouses

Baghouses, or fabric filter systems, filter particles through fabric filtering systems (bags). Particles are caught on the surface of the bags, while the cleaned flue gas passes through. To minimise pressure drop, the bags must be cleaned periodically as the dust layer builds up. Fabric filters can achieve the highest particulate collection efficiency of all particulate control devices. Most hot mix asphalt plants with baghouses use them for process and fugitive emissions control. The captured dust from these devices is usually returned to the production process.

### 4.1.5 Venturi Scrubbers

Venturi scrubbers (sometimes referred to as high energy wet scrubbers) are used to remove coarse and fine particulate matter. Flue gas passes through a venturi tube while low-pressure water is added at the throat. The turbulence in the venturi promotes intimate contact between the particles and the water. The wetted particles and droplets are collected in a cyclone spray separator (sometimes called a cyclonic demister). Venturi scrubbers are often used in similar applications to baghouses.

In addition to controlling particulate emissions, the venturi scrubber is likely to remove some of the process organic emissions from the exhaust gas. While the high-pressure venturi scrubber is reliable at controlling  $PM_{10}$ , it requires considerable attention and daily maintenance to maintain a high degree of particulate removal efficiency.

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.

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## 4.2 Fugitive Particulate Emissions Control

### 4.2.1 Driving Surfaces

Unpaved driving surfaces are commonly maintained by utilising wet-down techniques using water or, more seldom, other agents. In some areas unpaved roads may alternatively be covered with crushed recycled materials with equal success. In recent years, there has been a trend toward paving the driving surfaces to eliminate fugitive particulates. Facilities with paved surfaces may additionally employ sweeping or vacuuming as maintenance measures to reduce PM<sub>10</sub> emissions.

### 4.2.2 Aggregate Stockpiles

Watering of the stockpiles is not generally used because of the burden it puts on the heating and drying process. Occasionally, crusting agents may be applied to aggregate piles. These crusting agents serve fairly well to mitigate fugitive dust emissions in these instances. There are many variables that affect the fugitive dust emissions from stockpiles, including moisture content of the material, amount of fines (<200 mesh), and age of pile, ie older piles tend to loose their surface fines. Pre-washed aggregate, from which fines have been removed, may be used for additional PM<sub>10</sub> control.

## 4.3 VOC Control

Volatile organic compounds (VOCs) will be defined for the National Pollutant Inventory and this definition will be available through the NPI website:

<http://www.npi.gov.au>

Once the exhaust stream cools after discharge from the process stack, some VOCs condense to form a fine liquid aerosol or *blue smoke* plume. A number of process modifications or restrictions have been introduced to reduce blue smoke, including installation of flame shields, rearrangement of flights inside the drum, adjustments of the asphalt injection point, and other design changes. Periodic burner tune-ups may reduce VOC emissions substantially. Burner combustion air can be optimised to reduce emissions by monitoring the pressure drop across induced draft burners with a photohelic device tied to an automatic damper that adjusts the exhaust fan.

Condensing the vapours with air-cooled vent pipes can reduce organic vapours from heated bitumen storage tanks. In some cases, tank emissions may be routed back to combustion units. Organic emissions from heated bitumen storage tanks may also be controlled with carbon canisters on the vents or by other measures such as condensing precipitation or stainless steel shaving condensers. Although not common, organic emissions from tanker loading of bitumen can be controlled by venting into the dryer.

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## **4.4 Sulfur Dioxide Control**

### **4.4.1 Low Sulfur Fuel**

This approach to reduce sulfur dioxide ( $\text{SO}_2$ ) emissions reduces the sulfur fed to the combustor by burning low sulfur fuels. Fuel blending is the process of mixing higher sulfur content fuels with lower sulfur fuels, such as low sulfur oil. The goal of effective fuel blending is to provide a fuel supply with reasonably uniform properties that meet the blend specification, generally including sulfur content, heating value, and moisture content.

### **4.4.2 Aggregate Adsorption**

Alkaline aggregate, (ie. limestone), may adsorb sulfur compounds from the exhaust gas. In exhaust streams controlled by baghouses,  $\text{SO}_2$  may be reduced by limestone dust that coats the baghouse filters. Consequently, limestone aggregate may maximise the removal of sulfur compounds. A venturi scrubber may also adsorb sulfur compounds from the exhaust gas with recirculated water containing limestone.

## **4.5 Nitrogen Oxides Control**

### **4.5.1 Low Nitrogen Fuels**

Fuels lower in nitrogen content may reduce some  $\text{NO}_x$  emissions. At temperatures above  $1300^\circ\text{C}$ , however, conversion from high-nitrogen fuels to low-nitrogen fuels may not substantially reduce  $\text{NO}_x$  emissions, as thermal  $\text{NO}_x$  contributions will be more significant. Consequently,  $\text{NO}_x$  emissions are generally inversely related to CO emissions.

Staged combustion systems, such as low  $\text{NO}_x$  burners that are used to reduce  $\text{NO}_x$  emissions in other industries, are not generally employed in the hot mix asphalt industry due to economic and engineering considerations. Recirculation of the exhaust gas may be precluded by the relatively high moisture content (around 30 percent) of the gas stream. Exhaust recirculation in these instances may cause some flame quenching around the edges and could contribute to higher VOC and CO emissions when sealed burners are not used.

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## 5.0 Estimating Emissions

When a threshold has been triggered, emissions need to be calculated and reported to the NPI for each environmental medium to which emissions occur, (ie. to water, land, and atmosphere). The following sections describe emission estimation techniques for undertaking these calculations.

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

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

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

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

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

The **usage** 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.

Table 2 lists the variables and symbols used in the emission estimation techniques throughout this section.

**Table 2 - List of Variables and Symbols**

Variable	Symbol	Units
Concentration	$C_i$	parts per million volume dry at STP
Molecular weight	MW	kg per kg-mole
Molar volume @ STP (standard temperature and pressure)	V	22.4 m <sup>3</sup> per kg-mole @ 0 °C and 101.3 kPa
Flow rate	$Q_a$	actual cubic metres per second, m <sup>3</sup> /sec
Flow rate	$Q_d$	cubic metres per second, m <sup>3</sup> /sec
Emissions	$E_i$	generally kg per hour of pollutant i
Annual emissions	$E_{kpy,i}$	kg per year of pollutant i
Filter catch	$C_f$	grams, g
Fuel use	$Q_f$	generally, kg/hr
PM <sub>10</sub> concentration	$C_{PM}$	g/m <sup>3</sup>
Metered volume at standard temperature and pressure	$V_{m,STP}$	cubic metres, m <sup>3</sup>
Moisture	moist <sub>R</sub>	percent, %
Temperature	T	degrees Celsius, ° C
Asphalt production	A	tonne per year, tonne/yr
Annual operating hours	OpHrs	hour per year, hr/yr

Source: Queensland Department of Environment and Heritage, 1998.

## 5.1 Using Sampling Data

Stack sampling test reports often provide emissions data in terms of kg per hour or gram per m<sup>3</sup> (dry standard cubic metre). Annual emissions for NPI reporting can be calculated from these data using Equation 1 or Equation 2. Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

This section shows how to calculate emissions in kg per hour based on stack sampling data and then how to convert this to an annual emissions figure. Example calculations are given to determine PM<sub>10</sub> emissions, although the same calculations can be applied for estimating emissions of other NPI-listed substances from stack sampling reports.

An example summary of a test method is shown in Table 3. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of the test run include gas velocity and moisture content, which are used

to determine exhaust gas flow rates in dry standard m<sup>3</sup>/s. The filter weight gain is determined gravimetrically, and divided by the volume of gas sampled (as shown in Equation 1) to determine the PM concentration in g/m<sup>3</sup>/sec. Note that this example does not present the condensable PM emissions.

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

Equation 1 indicates how to calculate the concentration of a substance from the weight of the substance and the volume of air sampled:

**Equation 1**

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

where:

$$\begin{aligned} C_{PM} &= \text{concentration of PM or gram loading (g/m}^3\text{)} \\ C_f &= \text{filter catch (g)} \\ V_{m,STP} &= \text{metered volume of sample at STP (m}^3\text{)} \end{aligned}$$

Equation 2 can be used to convert the concentration of a substance calculated in Equation 1 to an hourly emission of the substance:

**Equation 2**

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

where:

$$\begin{aligned} E_{PM} &= \text{hourly emissions of PM (kg/hr)} \\ Q_d &= \text{stack gas volumetric flow rate (m}^3\text{/s)} \\ 3.6 &= \text{3 600 seconds per hour multiplied by 0.001 kilogram per hour} \end{aligned}$$

Application of Equation 1 and Equation 2 is illustrated in Example 1 using the stack sample test results given in Table 3.

**Table 3 - 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 (m <sup>3</sup> /s)		$1.67 * 10^{-4}$	$1.67 * 10^{-4}$	$1.67 * 10^{-4}$
Standard metered volume (m <sup>3</sup> )	$V_{m,STP}$	1.185	1.160	1.163
Volumetric flow rate (m <sup>3</sup> /s), dry	$Q_d$	8.48	8.43	8.45
Concentration of particulate (g/m <sup>3</sup> )	$C_{PM}$	0.0718	0.0387	0.0537

Source: Queensland Department of Environment and Heritage, 1998.

### Example 1 - Using Sampling Data

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

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

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use Equation 3 to calculate the dry particulate emissions in kg per hour from these types of test results.

### Equation 3

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

where:

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

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM<sub>10</sub> from total PM emissions, a size analysis may need to be undertaken. The weight PM<sub>10</sub> fraction can then be multiplied by the total PM emission rate to produce PM<sub>10</sub> emissions. Alternatively, assume that 100% of PM emissions are PM<sub>10</sub>; ie assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less ie. ≤10µm.

To calculate moisture content use Equation 4.

**Equation 4**

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

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

where

- moist<sub>R</sub> = moisture content, %
- g<sub>moist</sub> = moisture collected, g
- V<sub>m,STP</sub> = metered volume of sample at STP, m3
- ρ<sub>STP</sub> = dry density of stack gas sample, kg/m3 at STP  
 {if the density is not known a default value of 1.62 kg/m3 may be used. This assumes a dry gas composition of 50% air, 50% CO<sub>2</sub>}

**Example 2 – Calculating Moisture Percentage**

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

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

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

**5.2 Using 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 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, and/or duration of the activity emitting the substance (eg. kilograms of sulfur dioxide emitted per tonne of bitumen produced).

Emission factors are used to estimate a facility's emissions by Equation 5.

### Equation 5

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

where :

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

Example 3 illustrates the application of Equation 5.

Emission factors developed from measurements for a specific mixer or dryer 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 are measured from one dryer or mixer, an emission factor can be developed and applied to similar units. You are required to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

### Example 3 - Using Emission Factors

Table 7 shows that 0.0032 kg of acetone is emitted for each tonne of hot mix asphalt produced from a natural gas-fired dryer in both batch and drum mix asphalt plants. It is assumed that the asphalt plant operates for 1200 hours per year and that average production rate is 250 tonne per hour. Annual uncontrolled emissions can be calculated by application of Equation 5.

$$\begin{aligned} EF_{\text{acetone}} &= 0.0032 \text{ kg/tonne} \\ \text{Asphalt production rate} &= 250 \text{ tonne/hour} \end{aligned}$$

$$\begin{aligned} E_{kpy,\text{acetone}} &= [A * OpHrs] * EF_{\text{acetone}} * [1 - (CE_i/100)] \\ E_{kpy,\text{acetone}} &= 250 \text{ tonne/hr} * 1200 \text{ hr/yr} * 0.0032 \text{ kg/tonne} \\ E_{kpy,\text{acetone}} &= 960 \text{ kg/year} \end{aligned}$$

The facility operator has installed a flame shield in the drum mixer, which effectively reduces VOC emissions by 30 percent. Controlled emissions can now be calculated.

$$\begin{aligned} E_{kpy,\text{acetone}} &= 960 \text{ kg/yr} * [1 - (CE_i/100)] \\ &= 960 \text{ kg/yr} * [1 - (30/100)] \\ &= 672 \text{ kg/yr} \end{aligned}$$

**Table 4 - Particulate Matter (PM<sub>10</sub>) Emission Factors for Asphalt Plants**

Process	Batch Mix Asphalt Plants		Drum Mix Asphalt Plants <sup>b</sup>	
	PM <sub>10</sub> <sup>a</sup> (kg/tonne)	Emission Factor Rating	PM <sub>10</sub> <sup>a</sup> (kg/tonne)	Emission Factor Rating
<b>Natural gas-fired dryer:</b>				
Uncontrolled	2.2	E	2.2	D
Fabric filter	0.0098	D	0.0041	D
<b>Oil-fired dryer:</b>				
Uncontrolled	2.2	E	2.2	D
Fabric filter	0.03	D	0.015	D

Source: USEPA Document AP-42 (1995).

<sup>a</sup> Factor units are kg of PM<sub>10</sub> emitted per tonne of asphalt produced.

<sup>b</sup> Includes both parallel and counter flow asphalt plants.

**Table 5 - Emission Factors for CO, NO<sub>x</sub>, SO<sub>2</sub> and VOCs**

Process	Emission Factor (kg/tonne) <sup>a,c</sup>			
	CO	NO <sub>x</sub>	SO <sub>2</sub>	VOCs <sup>d</sup>
<b>Batch mix asphalt plants:</b>				
Natural gas-fired dryer	0.17	0.013	0.0025	0.0072
Oil-fired dryer	0.035	0.084	0.12	0.02
<b>Drum asphalt plants<sup>b</sup>:</b>				
Natural gas-fired dryer	0.028	0.015	0.0017	0.022
Oil-fired dryer	0.018	0.038	0.028	0.03

Source: USEPA Document AP-42 Ch. 11.1-12 (1995).

<sup>a</sup> Factor units are kg of pollutant emitted per tonne of asphalt produced.

<sup>b</sup> Includes both parallel and counter flow asphalt plants.

<sup>c</sup> All emission factors have an uncertainty rating of E.

<sup>d</sup> Converted from TOC (expressed as methane) in USEPA AP 42, Ch. 11.1-12. By using an average ratio of (MW of VOC) to (wt of carbon in that VOC) = 1.15. (Derived from the State of California Air Resources Board, *Identification of Volatile Organic Compound Species Profiles*, ARB Speciation Manual, Volume 1, August 1991, Table II, VOC Species Profiles 715 and 716.

**Table 6 - Controlled\* Emission Factors for Metals from Asphalt Plants**

Process	Substance	Emission Factor (kg/tonne)	
		Drum Asphalt Plant <sup>a,b,c</sup>	Batch Mix Asphalt Plant <sup>a,b</sup>
Dryer	Arsenic	$5.5 * 10^{-7}$	$3.3 * 10^{-7}$
	Beryllium	ND	$1.1 * 10^{-7}$
	Cadmium	$2.2 * 10^{-7}$	$4.2 * 10^{-7}$
	Chromium (total)	$6.0 * 10^{-6}$	$4.5 * 10^{-7}$
	Hexavalent chromium	ND	$4.9 * 10^{-9}$
	Copper	$3.1 * 10^{-6}$	$1.8 * 10^{-6}$
	Lead	$1.7 * 10^{-6}$	$3.7 * 10^{-7}$
	Manganese	$5.5 * 10^{-6}$	$5.0 * 10^{-6}$
	Mercury	$3.7 * 10^{-9}$	$2.3 * 10^{-7}$
	Nickel	$7.5 * 10^{-6}$	$2.1 * 10^{-6}$
	Selenium	ND	$4.6 * 10^{-8}$
	Zinc	$2.1 * 10^{-5}$	$3.4 * 10^{-6}$

Source: USEPA Document AP-42 (1995).

\* Controlled by fabric filter.

ND = no data.

<sup>a</sup> Units are kg of listed metal emitted per tonne of hot mix asphalt produced.

<sup>b</sup> Emission Factor Rating: E

<sup>c</sup> Includes both parallel and counter flow asphalt plants.

**Table 7 - Emission Factors for Organics from Drum and Batch Mix Asphalt Plants**

Process	Substance	Emission Factor <sup>a,c</sup> (kg/tonne)	
		Batch Mix Asphalt Plant	Drum Asphalt Plant <sup>d</sup>
Natural gas - fired dryer  (Natural gas or LPG (propane) fired in drum mix plants)	Acetone	3.2 * 10 <sup>-3</sup>	ND
	Acetaldehyde	3.2 * 10 <sup>-4</sup>	ND
	Benzene	1.7 * 10 <sup>-4</sup>	6.0 * 10 <sup>-4</sup>
	Formaldehyde	4.3 * 10 <sup>-4</sup>	1.8 * 10 <sup>-3</sup>
	Formaldehyde (wet scrubber) <sup>b</sup>	ND	7.9 * 10 <sup>-4</sup>
	Toluene	8.8 * 10 <sup>-4</sup>	1.0 * 10 <sup>-4</sup>
	Xylenes	2.1 * 10 <sup>-3</sup>	2.0 * 10 <sup>-4</sup>
	<b>PAHs<sup>c</sup>:</b>		
	2-Chloronaphthalene	ND	8.9 * 10 <sup>-7</sup>
	2-Methylnaphthalene	3.8 * 10 <sup>-5</sup>	3.7 * 10 <sup>-5</sup>
	Acenaphthene	6.2 * 10 <sup>-7</sup>	6.4 * 10 <sup>-7</sup>
	Acenaphthylene	4.3 * 10 <sup>-7</sup>	4.2 * 10 <sup>-6</sup>
	Anthracene	1.5 * 10 <sup>-7</sup>	1.0 * 10 <sup>-7</sup>
	Pyrene	3.1 * 10 <sup>-8</sup>	2.3 * 10 <sup>-7</sup>
	Benzo(a)anthracene	2.3 * 10 <sup>-9</sup>	1.0 * 10 <sup>-7</sup>
	Benzo(a)pyrene	ND	4.6 * 10 <sup>-9</sup>
	Benzo(b)fluoranthene	2.3 * 10 <sup>-9b</sup>	5.1 * 10 <sup>-8</sup>
	Benzo(e)pyrene	ND	5.2 * 10 <sup>-8</sup>
	Benzo(g,h,i)perylene	ND	1.9 * 10 <sup>-8</sup>
	Benzo(k)fluoranthene	1.2 * 10 <sup>-8</sup>	2.6 * 10 <sup>-8</sup>
	Chrysene	3.9 * 10 <sup>-9</sup>	1.8 * 10 <sup>-7</sup>
	Dibenzo(a,h)anthracene <sup>b</sup>	ND	1.3 * 10 <sup>-9</sup>
	Fluoranthene	1.6 * 10 <sup>-7</sup>	3.0 * 10 <sup>-7</sup>
	Fluorene	9.8 * 10 <sup>-7</sup>	2.7 * 10 <sup>-6</sup>
	Ideno(1,2,3-cd)pyrene	ND	3.6 * 10 <sup>-9</sup>
	Phenanthrene	1.6 * 10 <sup>-6</sup>	4.2 * 10 <sup>-6</sup>
	Perylene <sup>b</sup>	ND	6.2 * 10 <sup>-9</sup>
	Naphthalene	2.1 * 10 <sup>-5</sup>	2.4 * 10 <sup>-5</sup>
	Total PAH <sup>c</sup>	6.3 * 10 <sup>-5</sup>	7.5 * 10 <sup>-5</sup>
	Oil-fired dryer	Acetone	ND
Acetaldehyde		ND	6.5 * 10 <sup>-4</sup>
Benzene		ND	2.0 * 10 <sup>-4</sup>
Formaldehyde		1.6 * 10 <sup>-3 c</sup>	1.2 * 10 <sup>-3</sup>
Formaldehyde (wet scrubber) <sup>b</sup>		ND	2.6 * 10 <sup>-4</sup>

**Table 7 - Emission Factors for Organics from Drum and Batch Mix Asphalt Plants  
cont'**

Process	Substance	Emission Factor <sup>a,e</sup> (kg/tonne)	
		Batch Mix Asphalt Plant	Drum Asphalt Plant <sup>d</sup>
	Toluene	ND	$3.7 * 10^{-4}$
	Xylenes	ND	$8.2 * 10^{-5}$
	<b>PAHs<sup>c</sup></b>		
	2-Methylnaphthalene	$3.0 * 10^{-5}$	$8.5 * 10^{-5}$
	Acenaphthylene	ND	$1.1 * 10^{-5}$
	Anthracene	ND	$1.8 * 10^{-6}$
	Fluorene	ND	$8.5 * 10^{-6}$
	Fluoranthene	$1.2 * 10^{-5}$	ND
	Phenanthrene	$1.8 * 10^{-5c}$	$2.8 * 10^{-5}$
	Naphthalene	$2.2 * 10^{-5}$	$1.6 * 10^{-4}$
	Pyrene	$2.7 * 10^{-5}$	$1.5 * 10^{-6b}$
	<b>Total PAH<sup>c</sup></b>	$1.1 * 10^{-4}$	$3 * 10^{-4}$

Source: USEPA Document AP-42 (1995).

ND = no data.

<sup>a</sup> Units are kg of substance emitted per tonne of hot mix asphalt produced.

<sup>b</sup> Emission Factor Rating: E

<sup>c</sup> To report emissions of PAHs, apply the emission factor for Total PAHs only. Emission factors for individual PAHs have been provided to assist in assessing the validity of the emission factors provided and in evaluating any source testing procedures undertaken.

<sup>d</sup> Includes both parallel and counter flow asphalt plants.

<sup>e</sup> All emission factors have an uncertainty rating of D except where noted.

**Table 8 - Emission Factors for Organics from Asphalt Hot Oil Heaters**

Process	Substance	Emission Factor <sup>d</sup> (kg/L) <sup>a</sup>
Hot oil heater fired with distillate fuel oil	Formaldehyde	0.0032
	<i>Polycyclic aromatic hydrocarbons (PAH)<sup>b</sup>:</i>	
	Acenaphthene	$6.4 * 10^{-8}$
	Acenaphthylene	$2.4 * 10^{-8}$
	Anthracene	$2.2 * 10^{-8}$
	Benzo(b)fluoranthene	$1.2 * 10^{-8}$
	Fluoranthene	$5.3 * 10^{-9}$
	Fluorene	$3.8 * 10^{-9}$
	Naphthalene	$2 * 10^{-6}$
	Phenanthrene	$5.9 * 10^{-7}$
	Pyrene	$3.8 * 10^{-9}$
	Total PAH <sup>b</sup>	$2.7 * 10^{-6}$
	<i>Polychlorinated Dioxins and Furans<sup>c</sup>:</i>	
	1,2,3,7,8,9-hexachloro dibenzo dioxin (1,2,3,7,8,9-HxCDD)	$9.1 * 10^{-14}$
	1,2,3,4,7,8-hexachloro dibenzo dioxin (1,2,3,4,7,8-HxCDD)	$8.3 * 10^{-14}$
	Hexachloro dibenzo dioxin (HxCDD)	$7.4 * 10^{-13}$
	1,2,3,4,6,7,8-heptachloro dibenzo dioxin (1,2,3,4,6,7,8-HpCDD)	$1.8 * 10^{-12}$
	Heptachloro dibenzo dioxin (HpCDD)	$2.4 * 10^{-12}$
	Octochloro dibenzo dioxin (OCDD)	$1.9 * 10^{-11}$
	Tetrachloro dibenzo furan (TCDF)	$4 * 10^{-13}$
	Pentachloro dibenzo furan (PeCDF)	$5.8 * 10^{-14}$
	Hexachloro dibenzo furan (HxCDF)	$2.4 * 10^{-13}$
	Heptachloro dibenzo furan (HpCDF)	$1.2 * 10^{-12}$
	1,2,3,4,6,7,8-heptachloro dibenzo furan (1,2,3,4,6,7,8-HpCDF)	$4.2 * 10^{-13}$
	Octachloro dibenzo furan (OCDF)	$1.4 * 10^{-12}$
	Total Dioxins and Furans <sup>c</sup>	$2.8 * 10^{-11}$

Source: USEPA Document AP-42 (1995).

<sup>a</sup> Units are kg of substance emitted per litre of fuel consumed. The table includes data from both parallel flow and counter flow drum mix dryers. Organic compound emissions from counter flow systems are expected to be less than those from parallel flow systems, but available data is insufficient to quantify accurately the difference in these emissions.

<sup>b</sup> To report emissions of PAHs, apply the emission factor for Total PAHs only. Emission factors for individual PAHs are provided to assist in assessing the validity of the emission factors and evaluating any source testing undertaken.

<sup>c</sup> To report emissions of dioxins and furans, apply the emission factor for Total Dioxins and Furans only. Emission factors for individual substances are provided to assist in assessing the validity of the emission factors and evaluating any source testing undertaken.

<sup>d</sup> All emission factors have an uncertainty rating of E.

### 5.3 Using Fuel Analysis Data

Fuel analysis can be used to predict SO<sub>2</sub> and other emissions based on application of conservation laws, if fuel rate (Q<sub>f</sub>) 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 may be converted into other compounds during the combustion process.

Equation 6 can be used in fuel analysis emission calculations:

#### Equation 6

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

where:

E <sub>kpy, i</sub>	=	emissions of pollutant i, kg/yr
Q <sub>f</sub>	=	fuel use, kg/hr
MW <sub>p</sub>	=	molecular weight of pollutant emitted, kg/kg-mole
EW <sub>f</sub>	=	elemental weight of substance in fuel, kg/kg-mole
OpHrs	=	operating hours, hr/yr

For example, SO<sub>2</sub> emissions from oil combustion can be calculated based on the known concentration of sulfur in the oil. This approach assumes complete conversion of sulfur to SO<sub>2</sub>. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO<sub>2</sub> (MW = 64) are emitted. The application of Equation 6 is illustrated by Example 4.

#### Example 4 - Using Fuel Analysis

This example shows how SO<sub>2</sub> emissions can be calculated from oil combustion based on fuel analysis results and fuel flow information using Equation 6. The asphalt plant is assumed to operate for 1200 hours per year.

Assume a given Q <sub>f</sub>	=	2000 kg/hr
Weight percent sulfur in oil	=	1.17 %

$$\begin{aligned} E_{\text{kpy}, \text{SO}_2} &= Q_f * \text{pollutant concentration in fuel} * (MW_p / EW_f) * 1200 \\ &= (2000) * (1.17 / 100) * (64 / 32) * 1200 \text{ hr/yr} \\ &= 46.8 \text{ kg/hr} * 1200 \text{ hr/yr} \\ &= 56\,160 \text{ kg /yr} \end{aligned}$$

### 5.4 Using CEMS Data

To monitor SO<sub>2</sub>, NO<sub>x</sub>, VOC, and CO emissions using a continuous emission monitoring system (CEMS), a facility uses a pollutant concentration monitor, which measures concentration in parts per million by volume dry air (ppm). 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 generally run with high excess

air to remove the moisture out of the drum. Emission rates (kg/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 9 presents example CEMS data output averaged for three periods for a parallel flow drum mixer. The output includes pollutant concentrations in parts per million on a volume dry air basis (ppm), diluent (O<sub>2</sub> or CO<sub>2</sub>) concentrations in percent on a volume dry basis (%), and emission rates in kilograms per hour (kg/hr). This data represents a *snapshot* of a drum mixer operation. While it is possible to determine total emissions of an individual pollutant over a given time period from this data, assuming the CEMS operates properly all year long, an accurate emission estimate can be made by adding the hourly emission estimates, if the CEMS data is representative of typical operating conditions.

Although CEMS can report real-time hourly emissions automatically, it may be necessary to manually estimate annual emissions from hourly concentration data. This section describes how to calculate emissions for 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, facilities should develop a protocol for collecting and averaging the data in order that the estimate satisfies their respective State or Territory environment agency requirements for NPI reporting.

**Table 9 - Example CEMS Output for a Parallel Flow Drum Mixer Firing Waste Fuel Oil**

Time	O <sub>2</sub> (% by volume)	Concentration (C) (ppm <sub>vd</sub> )				Gas Flow	Asphalt Rate (A)
		SO <sub>2</sub>	NO <sub>x</sub>	CO	VOC	Rate (Q)	(tonnes /hour)
1	10.3	150.9	142.9	42.9	554.2	8.52	290
2	10.1	144.0	145.7	41.8	582.9	8.48	293
3	11.8	123.0	112.7	128.4	515.1	8.85	270

Source: Queensland Department of Environment and Heritage, 1998.

Hourly emissions can be calculated from concentration measurements as shown in Equation 7.

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**Equation 7**

$$E_i = (C * MW * Q_d * 3\,600) / [22.4 * (T+273/273) * 10^6]$$

where:

$E_i$	=	emissions of pollutant i, kg/hr
$C$	=	pollutant concentration, ppm <sub>vd</sub>
$MW$	=	molecular weight of the pollutant, kg/kg-mole
$Q_d$	=	stack gas volumetric flow rate, m <sup>3</sup> /s, dry
$3\,600$	=	conversion factor, s/hr
$22.4$	=	volume occupied by one mole of gas at standard temperature and pressure (0°C and 101.3 kPa), m <sup>3</sup> /kg-mole
$T$	=	temperature of gas sample, °C

Actual emissions in kilograms per year can be calculated by multiplying the emission rate in kg/hr by the number of actual operating hours (OpHrs) as shown in Equation 8.

**Equation 8**

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

where:

$E_{kpy,i}$	=	annual emissions of pollutant i, kg/yr
$E_i$	=	hourly emissions of pollutant i, kg/hr
OpHrs	=	annual operating hours, hr/yr

Emissions in kilograms of pollutant per tonne of asphalt produced can be calculated by dividing the emission rate in kg per hour by the asphalt production rate (tonne/hr) during the same period. Equation 9 illustrates this calculation. It should be noted that the emission factor calculated below assumes that the selected time period (ie. hourly) is representative of annual operating conditions and longer time periods should be used for NPI reporting where they are available.

**Equation 9**

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

where:

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

Example 5 illustrates the application of Equation 7, Equation 8, and Equation 9.

### Example 5 - Using CEMS Data

This example shows how SO<sub>2</sub> emissions can be calculated using Equation 7 based on the CEMS data for Time Period 1 shown in Table 9, and an exhaust gas temperature of 150°C (423K).

$$\begin{aligned} E_{SO_2,1} &= (C * MW * Q * 3\ 600) / [(22.4 * (T+273/273) * 10^6)] \\ &= (150.9 * 64 * 8.52 * 3\ 600) / [22.4 * (423/273) * 10^6] \\ &= 296\ 217\ 907 / 34\ 707\ 692 \\ &= 8.53\text{kg/hr} \end{aligned}$$

For Time Period 2, also at 150°C

$$E_{SO_2,2} = 8.11\text{kg/hr}$$

For Time Period 3, also at 150°C

$$E_{SO_2,3} = 7.23\text{kg/hr}$$

Say representative operating conditions for the year are:

$$\begin{aligned} \text{Period 1} &= 1500 \text{ hr} \\ \text{Period 2} &= 2000 \text{ hr} \\ \text{Period 3} &= 1800 \text{ hr} \end{aligned}$$

Total emissions for the year are calculated by adding the results of the three Time Periods using Equation 8:

$$\begin{aligned} E_{kpy,SO_2} &= E_{SO_2,1} * \text{OpHrs} + E_{SO_2,2} * \text{OpHrs} + E_{SO_2,3} * \text{OpHrs} \\ &= (8.53 * 1500) + (8.11 * 2000) + (7.23 * 1800) \text{ kg} \\ &= 42021 \text{ kg/yr} \end{aligned}$$

Emissions, in terms of kg/tonne of asphalt produced when operating in the same mode as time period 1, can be calculated using Equation 9:

$$\begin{aligned} E_{kpt,SO_2} &= E_{SO_2} / A \\ &= 8.53 / 290 \\ &= 2.94 * 10^{-2} \text{ kg SO}_2 \text{ emitted per tonne of clinker produced} \end{aligned}$$

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

## 5.5 Using Predictive Emission Monitoring (PEM)

Emissions from the hot mix asphalt process depend on several variables, which are discussed in Sections 2.0 and 3.0 of this Manual. For example, VOC process emissions for a given plant may vary with several parameters, including: the type of fuel burned; the relative quantities of asphalt constituents (recycled asphalt pavement, crumbed tyres, and emulsifiers); aggregate type and moisture content; the temperature of the asphalt constituents; the mixing zone temperature; and, fuel combustion rate. An example of emission monitoring that could be used to develop a PEM protocol for acceptable NPI

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reporting, would need to account for the variability in these parameters and, consequently, may require a complex testing algorithm.

To develop this algorithm, correlation testing of the process variables could be conducted over a range of potential operating conditions for a suite of NPI-listed substances including VOCs and SO<sub>2</sub>. Based on the test data, a mathematical correlation can be developed which predicts emissions using the various parameters. This method may be cost prohibitive for a single source and may need to be undertaken across the Australian hot mix asphalt industry generally.

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## **6.0 Emission Estimation Techniques: Acceptable Reliability and Uncertainty**

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

There are several techniques available for estimating emissions from hot mix asphalt plants. The technique chosen is dependent on available data, available resources, and the degree of accuracy sought by the facility in undertaking the estimate. In general, site-specific data is more accurate than industry averaged data, such as the emission factors presented in following sections of this Manual. However, this is not always the case as emission factors with an uncertainty rating of A, or even B, are potentially more accurate than source testing results.

This section discusses the techniques available for calculating emissions from hot mix asphalt plants and identifies the different methods of calculation available on a pollutant basis. These emission estimation techniques are listed in no particular order and the reader should not infer a preference based on the order they are listed in this section.

### **6.1 Stack and Pipe Sampling or Direct Measurement**

Stack and pipe sampling provides a snapshot of emissions during the period of the stack or pipe test. Stack and pipe tests are generally performed during either representative, (ie. normal), or worst case conditions, depending on the requirements of the facility operator or on the conditions of the State or Territory licensing requirements. For the purposes of reporting to the NPI, representative samples only should be collected. Stack samples are collected using probes inserted through a port in the stack wall or from the emission stream above the stack, and pollutants are collected in or on various media and sent to a laboratory for analysis. Emission rates are then determined by multiplying the pollutant concentration by the volumetric stack gas flow rate. Because there are many steps in the stack sampling procedures where errors can occur, only experienced stack testers should perform such tests.

From the pipe, representative liquid emission samples of known volume are collected. Samples are usually collected over a period of time allowing for a greater representation of the pollutant load of the emission waste-stream. Pollutant concentrations are obtained by dividing the amount of pollutant collected during the test by the volume of the sample.

### **6.2 Emission Factors**

Emission factors are available for many sources and processes within a facility and are based on the results of source tests performed at an individual facility or at one or more facilities within the hot mix asphalt industry sector. Basically, an emission factor is the pollutant emission rate relative to the level of source activity. The user should recognise that, in most cases, emission factors adopted for the NPI are averages of available industry-wide data, usually US or European and seldom Australian, with varying degrees of quality. Emission factors are, however, an acceptable technique for estimating emissions

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from all industry sectors and source categories for the NPI where estimations of emissions are required to quantify medium to long-term emission trends.

Every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited can be found in Section 7 of this Manual. The emission factor ratings will not form part of the public NPI database.

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

The EFR system is as follows:

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

### **6.3 Fuel Analysis**

Fuel analysis data can sometimes be used to predict emissions by applying mass conservation laws. For example, if the concentration of a pollutant, or pollutant precursor, in a fuel is known, emissions of that pollutant can be calculated by assuming that all of the pollutant is emitted or by adjusting the calculated emissions by the control efficiency. This approach is particularly appropriate for estimating emissions of SO<sub>2</sub> and metals where the sulfur and metal content of the fuel is known.

### **6.4 Continuous Emission Monitoring System (CEMS) and Predictive Emission Monitoring (PEM)**

A CEMS provides a continuous record of emissions over time. Various principles are employed to measure the concentration of pollutants in the gas or water stream. For air emissions, a CEMS is usually based on photometric measurements while for water emissions in-pipe measurements are taken. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas flow rate or stream flow rate for air and water emission respectively.

Continuous monitoring instruments can also measure stack gas flow rate; but it is more generally determined using manual methods, such as pitot tube traverse. At low pollutant

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concentrations, the accuracy of this method may decrease. Instrument drift can be problematic for CEMS and uncaptured data can create long-term, incomplete data sets.

PEM is based on developing a correlation between pollutant emission rates and process parameters. A PEM may be considered as a specialised usage of an emission factor and allows facilities to develop site-specific emission factors or emission factors more relevant to Australian conditions. Correlation tests must first be performed to develop this relationship. At a later time, emissions can then be calculated using process parameters to predict emission rates based on the results of the initial source test.

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## 7.0 References

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

- Combustion in Boilers; and
- Fuel & Organic Liquid Storage.