NPI Web

National Pollutant Inventory

# Emission Estimation Technique Manual

## for

# Combustion Engines
# Version 2.2

EA Web

*First published in February 1999*
*Revised - August 2000*
*Version 2.2 – 14 June 2002*

**ISBN:** 0642548072
www.npi.gov.au



NPI Web

## Disclaimer

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

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

# Erratum for Combustion Engines EET Manual (Version 2.2 – 22 March 2002).

| Page | Outline of alteration |
|---|---|
| 9 | Additional information about the use of direct measurement to determine emissions from engines. |
| 9 | Table added demonstrating the use of $CO/CO_2$ ratio to determine CO emissions from engines. |
| 12 | Corrected and inserted details of new tables added to manual. |
| 17 | Inserted details highlighting load factor should be used for emission estimates if engine power is used to estimate emissions. |
| 18 | Equation 6 inserted to highlight using load factor when using fuel consumption to determine emissions. |
| 19 | Table 7 provides additional transport emission factors based on diesel use. |
| 19 | Updated the CO emission factors in Table 8 to reflect lower levels emitted from LPG passenger vehicles. |
| 20 | Table 10 provides additional vehicle emission factors based on petrol fuel use. |
| 20 | Altered calculation step (step 2) to reflect new data provided. |

# Erratum for Combustion Engines EET Manual (Version 2.1 – 6 September 2000).

| Page | Outline of alteration |
|---|---|
| 17 | Table 6 – Emission factors for LPG engines based on LPG usage are added. |
| 18 | Table 9 – Load factor for forklifts has decreased from 0.5 to 0.2. |
| 19 | Equation 6 and text has been added to indicate the use of new emission factors from Table 6. |
| | Equation numbering after Equation 6 has altered. |
| 30 | Table 12 – Diesel $SO_2$ emission factors have increased from 4.92E-05$S_1$ and 1.66E-01$S_1$ to 4.92E-03$S_1$ and 1.66E+01$S_1$ respectively. |

Note:
1. The estimation techniques provided for LPG engines, Table 6, are the best we have currently available. These may be altered if more current data becomes available.
2. The erratum above does not include changes to numbering in the manual and small typographical changes. These smaller changes are indicated in the highlighted changes in the marked version of the manual.

EMISSION ESTIMATION TECHNIQUES
FOR
COMBUSTION ENGINES
TABLE OF CONTENTS

# EMISSION ESTIMATION TECHNIQUES FOR COMBUSTION ENGINES

## LIST OF FIGURES, TABLES AND EXAMPLES

# 1 Introduction

The purpose of 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 combustion engines.

The activities covered in this Manual apply to facilities using:

- Petrol and diesel industrial engines;
- Petrol, diesel and LPG light vehicles, commercial vehicles and trucks;
- Large stationary diesel and dual-fuel engines;
- Heavy-duty natural gas fired pipeline compressor engines and turbines

EET MANUAL: Combustion Engines

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 industry stakeholders.

NPI Guide

# 2 Processes and Emissions

The following section presents a brief description of combustion engines and identifies likely emission sources.

## 2.1 Process Descriptions

The engine categories addressed by this manual cover a wide variety of applications including petrol, diesel, LPG, dual-fuel and natural gas combustion engines. A dual-fuel engine uses both diesel and natural gas for fuel. Various other fuels are also accounted for. Combustion engines are used in a wide variety of equipment, for example: aerial lifts, forklifts, mobile refrigeration units, generators, irrigation pumps, industrial sweepers/scrubbers, material handling equipment (e.g. conveyors) and portable well-drilling equipment. In determining pollutant emissions it is the characteristics of the engine more than the equipment the engine drives that is important. Figure 1 illustrates the basic combustion engine process.

Often the term *internal combustion* is used. This simply refers to the fuel burning within the engine in contrast to external combustion (such as in a steam engine), where the combustion process is separate from the moving piston. In this manual the term *combustion engine* is used to mean internal combustion engine.

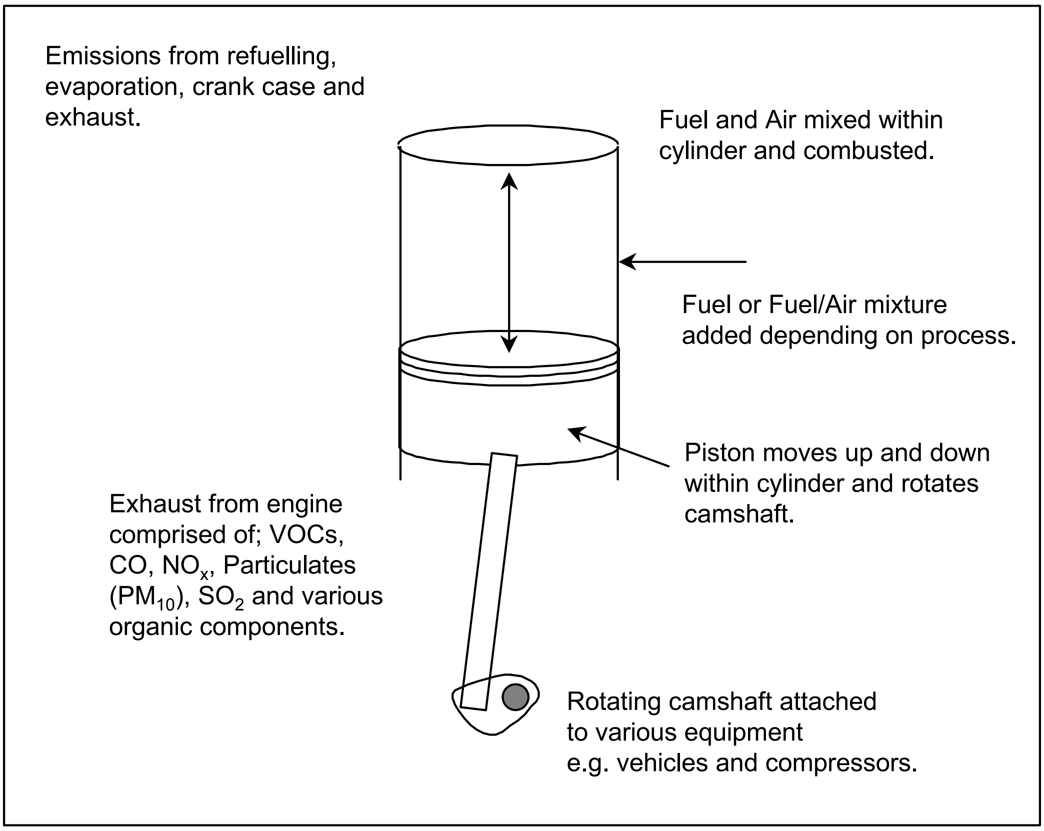


**Figure 1 Basic Combustion Engine Process**
Source: Queensland Department of Environment and Heritage 1998

### 2.1.1 Petrol and Diesel Industrial Engines

The three primary fuels for combustion engines are petrol, diesel (also called fuel oil No. 2) and natural gas. Petrol is used primarily for vehicles and small portable engines. Diesel is the most versatile fuel and is used in combustion engines of all sizes. The rated power of these engines is wide, up to 200 kW (270 hp) and over 1000 kW (1340 hp) for petrol and diesel engines respectively. Substantial differences in engine duty cycles exist, and it may be necessary when undertaking emissions estimations to make reasonable assumptions, as outlined in this manual, concerning fuel usage.

Combustion engines may be used to power vehicles of various types; such engines are covered in Section 3.4.1 to 3.4.4. Stationary engines are those that do not power vehicles but are used for some other operation and are covered in Sections 3.4.5 to 3.4.9. Stationary engines may be portable, for example, a compressor mounted on a truck or trailer.

### 2.1.2 Large Stationary Diesel and All Stationary Dual-Fuel Engines

A major use of large (greater than 450 kW) stationary diesel engines in Australia is in the oil and gas industry. These engines, grouped in clusters of three to five individual engines, supply mechanical power to operate drilling (rotary table), mud pumping and hoisting equipment, and may also be used to operate pumps or auxiliary power generators. Other frequent applications of large stationary diesel engines include electricity generation for isolated outback communities and stand-by services in hospitals and other facilities. Other uses include irrigation and cooling water pump operation.

Dual-fuel engines were developed to obtain maximum compression ignition performance and reduce natural gas usage, using a minimum of 5–6% diesel to ignite the natural gas. Large dual-fuel engines are used almost exclusively for electric power generation.

Estimating emissions from stationary engines is covered in Sections 3.4.5 to 3.4.9 and use of two different methods is utilised. The first method based on engine power and operating hours is covered in Section 3.4.6. The second method based on engine fuel consumption is covered in Section 3.4.8. Emission factors used to estimate stationary combustion engine emissions are in Table 13 to Table 16 for non-natural gas, Table 17 to Table 24 for liquid fuel engines and for heavy-duty natural gas engines and turbines as outlined in Table 2.

### 2.1.3 Heavy-Duty Natural Gas Fired Pipeline Compressor Engines and Turbines

Natural gas fired combustion engines are used in the natural gas industry at pipeline compressor and storage stations. The engines and gas turbines are used to drive compressors. At pipeline compressor stations engines or turbines are used to help transport natural gas to the next station. At storage facilities it is used to inject the natural gas into high-pressure underground cavities called natural gas storage fields. Although they can operate at a fairly constant load, pipeline engines or turbines must be able to operate under varying pipeline requirements. These diesel engines range from 600 to 3 750 kW (800 to 5 000 hp) and gas turbines range from 750 to 11 200 kW (1 000 to 15 000 hp).

Heavy-duty natural gas fired pipeline compressor engines and turbines are a class of stationary engine and the engine power technique, Section 3.4.6, or fuel consumption technique, Section 3.4.8, can be used to estimate emissions. The emission factors for this category of engines are in Table 17 to Table 24.

## 2.2 Emission Sources and Control Technologies

Emissions from combustion engines are released to the environment via various routes. These can be summarised as emissions to air, water and land, and are detailed in the Sections 2.2.1 to 2.2.3, respectively.

### 2.2.1 Emissions to Air

Pollutant emissions to air may be categorised as fugitive and point source emissions as described below:

- **Fugitive Emissions** - These are emissions that are not released through a vent or stack. Examples of fugitive emissions include volatilisation of vapour from vats or fuel tanks, open vessels, spills and materials handling. Emissions emanating from ridgeline roof-vents, louvres, open doors of a building, as well as equipment leaks and leaks from valves and flanges, are also examples of fugitive emissions. Emission Factors are the EETs usually used for determining fugitive emissions of pollutants.

- **Point Source Emissions** - These emissions flow into a vent or stack and are emitted through a single point source into the atmosphere. An example is the exhaust system of combustion engine powered equipment.

Most of the pollutants from combustion engines are emitted through the exhaust. Some volatile organic compounds (VOCs) escape from the crankcase as a result of blow-by (gases vented from the oil pan after they have escaped from the cylinder past the piston rings and from the fuel tank and carburettor due to evaporation). Nearly all the VOCs from diesel combustion engines enter the atmosphere from the exhaust. Crankcase blow-by is minor because VOCs are not present during compression of the fuel-air mixture and evaporative losses are insignificant in diesel engines due to the low volatility of diesel fuels. In general, evaporative losses are also negligible in engines using gaseous fuels, as these engines receive their fuel continuously from a pipe rather than from a fuel storage tank using a fuel pump.

The primary NPI pollutants emitted from combustion engines are: Total VOCs, carbon monoxide (CO), oxides of nitrogen ($NO_x$), particulate matter less than 10μm in aerodynamic diameter ($PM_{10}$), and $SO_2$. $PM_{10}$ includes both visible (smoke) and non-visible emissions. Other pollutants are also emitted in trace amounts as products of incomplete combustion. Ash and metallic additives in the fuel contribute to the particulate content of the exhaust.

The primary pollutant of concern from diesel and dual-fuel engines is $NO_x$, which forms readily due to high temperatures and pressure in combination with high fuel nitrogen content and excess air in the cylinder. In some cases lesser amounts of CO and organic compounds are emitted. The sulfur compounds, emitted mainly as $SO_2$, are directly related to fuel sulfur content. The $SO_2$ emissions will usually be low because of negligible sulfur content of diesel fuels and natural gas. The following paragraphs provide details on the mechanics of the various pollutant pathways from combustion engines. These pollutants, except VOCs as described above, are released via the combustion engine exhaust system.

***Carbon Monoxide (CO)***

CO is a colourless, odourless, relatively inert gas formed as an intermediate combustion product. It appears in the exhaust when the reaction of CO to $CO_2$ cannot proceed to completion. This situation occurs from lack of available oxygen near some fuel molecules during combustion, low gas temperature or short residence time in the cylinder. The oxidation rate of CO is limited by reaction kinetics and consequently can be accelerated to a limited extent only, by improvements in air and fuel mixing during combustion.

***Oxides of Nitrogen ($NO_x$)***

$NO_x$ formation occurs from three fundamentally different reactions and is released from the exhaust system. The principal source in combustion engines is thermal $NO_x$ from the thermal dissociation and subsequent reaction of nitrogen ($N_2$) and oxygen ($O_2$) molecules from the combustion air. Most thermal $NO_x$ is formed in high-temperature regions in the cylinder or combustor where combustion air has mixed sufficiently with the fuel to produce the peak temperature at the fuel/air interface. A component of thermal $NO_x$, prompt $NO_x$, is formed from early reactions of nitrogen intermediaries and hydrocarbon radicals from the fuel. Prompt $NO_x$ forms within the flame and is usually negligible compared with other thermal $NO_x$ formed.

The formation of fuel $NO_x$ occurs from the evolution and reaction with oxygen of fuel-bound nitrogen compounds. Natural gas has negligible chemically bound nitrogen in the fuel, and essentially all $NO_x$ formed is thermal $NO_x$. The formation of prompt $NO_x$ can make up a significant part of total $NO_x$ only under highly controlled situations where thermal $NO_x$ is suppressed; this is more prevalent with rich burn engines. The rates of these reactions are highly dependent on the fuel/air stoichiometric ratio, combustion temperature and residence time at combustion temperature.

The maximum thermal $NO_x$ production occurs with a slightly lean fuel/air mixture ratio because of the excess availability of oxygen for reaction; control of fuel/air stoichiometry is critical in achieving thermal $NO_x$ reductions.

Pre-mixing in lean burn engines is effective in suppressing $NO_x$ relative to rich burn engines. The thermal $NO_x$ generation decreases rapidly as the temperature drops below the adiabatic temperature. Therefore, maximum reduction of thermal $NO_x$ generation is achieved by control of both the combustion temperature and the stoichiometry.

The combustion in conventional design combustion engines is by diffusion flames characterised by regions of near stoichiometric fuel/air mixtures where temperatures are high and most $NO_x$ is formed. Since the localised $NO_x$ forming regions are at much higher temperatures than the adiabatic flame temperature for the overall mixture, the rate of $NO_x$ formation is dependent on the fuel/air mixing process. The mixing determines the prevalence of the high temperature regions, as well as the peak temperature attained. Adiabatic flame temperature or adiabatic temperature is the temperature achieved by a combustion process where no heat enters or leaves the system and is the maximum temperature that can be achieved for the given reactants (Reference 9, p. F-69 and http://www.commkey.net/braeunig/space/comb.htm).

***Particulate Matter 10 microns or less ($PM_{10}$)***

The amount of $PM_{10}$ generated from combustion engines and released via the exhaust system varies considerably. Liquid particulate matter is generally categorised as white smoke and appears during a cold start, idling or low load operation and occurs when the temperature within the quench layer is not high enough to promote ignition. Blue smoke is prevalent when there are oil leaks present and the oil undergoes partial combustion in the cylinders. Black smoke, called soot, is the most prevalent constituent of $PM_{10}$ and is essentially carbon particles formed from oxygen deficiency in the cylinder.

$PM_{10}$ emissions from combustion engines are non-detectable with conventional protocols unless the engines are operated in sooting conditions; however, $PM_{10}$ can arise from carryover of non-combustible trace constituents in the gas or from engine lubrication oil.

***Sulfur Dioxide ($SO_2$)***

Sulfur dioxide emissions are directly related to the fuel sulfur level and are released from the exhaust system. Essentially all sulfur present is oxidised to form $SO_2$. Sulfuric acid can also arise because of the production of sulfur trioxide and its subsequent reaction with water. Sulfuric acid reacts with basic substances to produce sulfates, which are fine particles that contribute to $PM_{10}$ emissions. Sulfur oxide emissions also contribute to engine corrosion.

***Organic Carbon (VOCs and PAHs)***

The pollutants commonly classified as hydrocarbons are composed of a wide variety of organic compounds that are emitted into the atmosphere mainly from the exhaust system when some of the fuel is unburned or partially burned during combustion. NPI-listed substances include Total VOCs and polycyclic aromatic hydrocarbons (PAHs). Most unburned hydrocarbon emissions result from fuel droplets that were transported or injected into the quench layer during combustion. This is the region immediately adjacent to the combustion chamber surfaces where heat transfer through the cylinder walls causes the temperature of the mixture to be too low for combustion.

Partially burned hydrocarbons can occur because of poor air and fuel mixing before or during combustion and incorrect air/fuel ratios in the cylinder during combustion due to poor adjustment of the engine fuel system. Other reasons are excessively large fuel droplets in diesel engines and low cylinder temperature due to excessive cooling through the cylinder walls or early cooling of the gases by expansion of the combustion volume caused by piston motion before combustion is completed.

In natural gas combustion some VOCs are carried over as unreacted constituents of the natural gas or the pyrolysis products of the heavier hydrocarbon constituents.

***Emission Control Technologies***

Air emission control technologies, such as electrostatic precipitators, fabric filters (baghouses) and wet scrubbers are commonly installed to reduce the particulate concentration in process off-gases. Where such emission abatement equipment is installed and emission factors from uncontrolled sources have been used in emission estimation, the collection efficiency of the abatement equipment needs to be accounted for. Guidance on applying emission reduction efficiency to emission factor equations is provided in Section 3.4.6.

With regard to emission controls for $PM_{10}$ (i.e., the various filters described above), in the absence of measured data or knowledge of the emission reduction efficiency for a particular piece of equipment, an estimate is assumed. In this case an emission reduction efficiency of 90% should be used in the emission factor equations, Equation 8 and Equation 9, to calculate the mass of pollutant emissions. This default should be used only if no other available emission reduction efficiency estimation is available.

### 2.2.2 Emissions to Water

From combustion engine use there is the possibility of spills and fugitive leaks into water bodies or stormwater drains. Since significant environmental hazards may be posed by emitting toxic substances to water, most facilities emitting NPI-listed substances from point sources to waterways are required by their relevant State or Territory environment agency to closely monitor and measure these emissions and take precautions to ensure leakages are isolated from waterways.

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

### 2.2.3 Emissions to Land

Emissions of substances to land include emissions of solid waste materials, slurries and sediments. Spills and leaks can occur during storage and distribution of fuel as well as during use in combustion engines. Emissions to land may contain NPI-listed substances. These emission sources can be broadly categorised as:

- surface impoundment of liquids and slurries
- unintentional leaks and spills

NPI Guide

Probable causes of emissions to land from facilities using engines are fuel leaks or liquid fuel spills. Other fugitive emissions can occur from oil leaks and maintenance activities.

## 2.3 Determining if Emissions Need to be Estimated and Reported

Whether or not emissions need to be estimated and reported as part of the NPI is dependent on various thresholds for a substance being exceeded. For the substances emitted from combustion engines the threshold is Category 2a or 2b and for some substances contained in fuel Category 1 or 1a. Further details for determining if a facility exceeds the various thresholds for reporting pollutant emissions are in the *NPI Guide* that is part of this industry handbook.

Category 2a contains a group of substances that are usually common products of combustion or other thermal processes. As with Category 2a, Category 2b contains substances that are common products of combustion or other thermal processes and additionally contains a range of trace metals that are emitted when some fuels such as coal are consumed.

The Category 2a and 2b thresholds are related to the amount of fuel or waste your facility burns. In the case of the 2b threshold, the amount of energy used and the maximum potential power consumption is also considered. If your facility exceeds the 2a or 2b threshold you must report emissions of all the 2a and 2b substances respectively as outlined in the *NPI Guide*.

# 3 Emission Estimation Techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in the *NPI Guide* that is part of this Industry Handbook.

In general, there are four types of emission estimation technique (EET), detailed in the *NPI Guide*, which may be used to estimate facility emissions:

- sampling or direct measurement;
- mass balance;
- fuel analysis or other engineering calculations; and
- emission factors.

NPI Guide

Select the EET (or combination 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 pollution 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 alternative EETs not outlined in this *Handbook* your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective EETs for the NPI substances relevant to this industry. However, the absence in this Manual of an EET for a substance does not necessarily mean that pollutant emission is not reported to the NPI. The obligation to report on all relevant emissions remains if emission reporting thresholds are exceeded.

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

In general, direct measurement is the most accurate method for characterising emissions. Where available, it should be used in preference to other EETs in this Manual. However, in many situations related to combustion engines the data required to complete pollutant emission estimates by direct measurement is not available and other EETs will need to be used. Additional direct measurement is not required under the NPI Measure. Direct monitoring may be undertaken as an element of other EETs that could be utilised to obtain estimates of pollutant emissions.

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 such as spills also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, i.e., the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean-up operations.

### 3.1 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. The NPI does not require you to undertake additional sampling and direct measurement to fulfil reporting requirements. For sampling data to be adequate and able to be used for NPI reporting purposes it would need to be collected over a significant period of time and be representative of operations for the whole year.

Direct measurement can be used to estimate emissions from combustion engines using exhaust samples from the engines used at the facility or similar engines under conditions equivalent to those at the facility. Appropriate sampling methods must be used and the calculations to estimate emissions must be correct. In particular the fuel to air ratio and the amount of air that is entrained with the exhaust prior to measurement of its composition must be accounted for.

It is not possible simply to analyse the exhaust emissions, obtain the concentration of NPI substances in exhaust and determine emissions of those substances. It is necessary to relate the concentration of substances in exhaust to fuel use and the overall exhaust emissions or to the total gas flow from the exhaust. The concentration of a substance alone cannot be used to determine emissions of that substance.

For example, CO emissions from a forklift, can be estimated using a direct-measurement technique by determining the $CO/CO_2$ ratio in the exhaust for different operating conditions and relating this to the carbon content of the fuel to determine the CO emissions per kilogram or litre of fuel. CO emissions can then be determined from the forklift's fuel use. Table 1 indicates the $CO/CO_2$ ratios that lead to specific CO emission factors for LPG engines.

If you need assistance to apply direct-measurement techniques to determine emissions of NPI substances contact a consultant specialising in the area.

**Table 1 Typical analysis results for an LPG (propane) powered forklift using 10% excess air indicating that the $CO/CO_2$ ratio is used to determine the CO emission factor**

| Concentration ppm CO (wet basis)[3] | CO EF (kg/kg fuel) | $CO/CO_2$ ratio (vol/vol) |
|---|---|---|
| 1.00E+02 | 1.80E-03 | 9.42E-04 |
| 5.00E+02 | 8.99E-03 | 4.73E-03 |
| 1.00E+03 | 1.80E-02 | 9.51E-03 |
| 2.00E+03 | 3.60E-02 | 1.92E-02 |
| 5.00E+03 | 9.01E-02 | 4.95E-02 |
| 1.00E+04 | 1.81E-01 | 1.04E-01 |
| 1.50E+04 | 2.72E-01 | 1.66E-01 |
| 2.00E+04 | 3.63E-01 | 2.35E-01 |
| 4.00E+04 | 7.33E-01 | 6.24E-01 |

Notes:
1. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.
2. EF – emission factor.
3. The concentration of CO in the exhaust (column 1 above) depends on the amount of excess air included in the exhaust and is not a direct indication of the emission levels of CO from the forklift tested.

### 3.1.1 Sampling Data

Stack sampling test reports often provide emissions data in terms of kg/h or g/m$^3$ (dry standard). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative operating conditions. This may require determinations for different process conditions and determining the contribution that each process condition makes to the overall pollutant emission. You should be aware that some tests undertaken as a State or Territory license condition may require that the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

### 3.1.2 Continuous Emission Monitoring System (CEMS) Data

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

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

## 3.2 Mass Balance

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

This is a very useful technique for certain classes of pollutant on the NPI, but is often a difficult technique to apply in the case of combustion engines.

## 3.3 Engineering Calculations

An engineering calculation is an estimation method based on physical/chemical properties (e.g. vapour pressure) of the substance and mathematical relationships (e.g. ideal gas law). The main combustion engine NPI pollutant for which this is a useful technique is $SO_2$. The amount of $SO_2$ emitted may be predicted based on the amount of sulfur in the fuel. The technique for completing the estimation of $SO_2$ from combustion is outlined in Section 3.3.1 and Example 1 below.

### 3.3.1 Estimation of $SO_2$ Emitted from Fuel Analysis

Fuel analysis is an example of a physical property used in an engineering calculation; it can be used to predict $SO_2$, based on application of the mass conservation relationship. The method relies on knowing or estimating the amount of fuel used. Other pollutants where this technique may be useful to estimate pollutant emission levels are metals such as lead.

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

$$E_{kpy,i} = Q_f * (C_f/100) * (MW_p/EW_f) * OpHrs \qquad \text{Equation 1}$$

where:

$E_{kpy,i}$ = emission of pollutant i, kg/yr

$Q_f$ = fuel use, kg/h

$C_f$ = amount of substance within fuel that leads to pollutant release, wt% of fuel

$MW_p$ = molecular weight of pollutant emitted, g/mole

$EW_f$ = elemental weight of substance in fuel, g/mole

OpHrs = operating hours of engine, h/yr

For instance, $SO_2$ emissions from combustion are calculated from the fuel sulfur levels available from fuel suppliers. This approach assumes complete conversion of sulfur to $SO_2$. Therefore, for every kilogram of sulfur ($EW_f$ = 32 g/mole) combusted, two kilograms of $SO_2$ ($MW_p$ = 64 g/mol) are emitted. An application of this EET is shown in Example 1.

***Example 1 - Using Fuel Analysis Data to Determine $SO_2$ Emission***

This example estimates annual engine $SO_2$ emission based on fuel sulfur level and annual usage using Equation 1 to determine $E_{SO2}$ for the year. The following data is available

$Q_f$ = 20 900 kg/h
$C_f$ = 0.117 wt% S
$MW_p$ = 64 g/mole
EW = 32 g/mole
OpHrs = 1 500 h/yr

$$E_{SO2} = Q_f * (C_f /100) * (MW_p / EW_f) * OpHrs$$

$$= 20\,900 * (0.117 /100) * (64 / 32) * 1\,500$$
$$= 73\,359 \text{ kg/yr}$$

If the annual fuel usage is in litres (L) the mass of fuel, $Q_f$, can be determined using the fuel density, which along with the fuel sulfur level, $C_f$, is available from the fuel supplier. Some details regarding fuel properties are in Appendix 1.

### 3.4 Estimating Emissions Using Emission Factors

Emission factors may be used to estimate pollutant emissions to the environment. In this Manual emission factors relate the quantity of pollutant emitted from an engine to its power or fuel consumption and, in the case of road-transport vehicles, the distance travelled. When an emission factor related to engine power is used, the annual engine operating hours are required. Different emission factors have different units. Emission factors based on engine power are expressed as kg of pollutant per kWh, factors based on fuel usage are kg of pollutant per $m^3$ of fuel and factors based on distance travelled are kg of pollutant per km travelled in the reporting year. For combustion engines examined in this Manual the fuel is either liquid or gas. The emission factors provided are from US, European and Australian sources.

Equation 2 shows the general equation for the use of an emission factor to estimate annual pollutant release and is included here as it is common to all NPI manuals using emission factor techniques. Equation 2 is NOT directly used in this Manual to estimate pollutants. Equation 3, 4, 5, 7 and 8 show the use of emission factors to estimate the pollutants emitted for combustion engines in different situations.

$$E_{kpy,i} = A * OpHrs * EF_i * [1 - (ER_i/100)] \qquad \text{Equation 2}$$

where :

$E_{kpy,i}$ = emission of pollutant i, kg/yr

A = activity rate, t/h

OpHrs = operating hours, h/yr

$EF_i$ = emission factor of pollutant i, kg/t

$ER_i$ = emission reduction efficiency for pollutant i, %

Industry-developed emission factors from specific process measurements may be used to estimate emissions at other sites. Should a company use several processes of similar operation and size, and emissions are measured from one such source, an emission factor could be developed and applied to similar sources. However, it is required to have newly developed emission factors reviewed and approved by State or Territory environment agencies prior to their use for NPI estimations.

In this Manual, combustion engines are classified as either combustion engines powering vehicles or combustion engines that are stationary. This Manual provides EETs for vehicles powered by combustion engines that are used on-site. Pollutant emissions from vehicles while used off-site are determined by the relevant State or Territory environment agencies. On-site refers to within the facility boundary. Combustion engine EETs for vehicles are outlined in Section 3.4.1. Stationary engines are those that do not propel a vehicle directly; they include power units for compressors, generators and pumps. Stationary engines may be mounted on or towed by vehicles. Stationary combustion engine EETs using emission factors are outlined in Sections 3.4.5 to 3.4.9.

A summary of where emission factors for different engines and conditions are located within this manual is in Table 2.

**Table 2 Emission Factor Summary for Different Engines and Fuels**

<table>
<tr><th colspan="3">Engine/Fuel</th><th>Table</th><th>Pollutants</th><th>Units</th></tr>
<tr><td rowspan="11">Vehicles</td><td rowspan="3">Road</td><td>Cars – Petrol, Diesel and LPG</td><td>Table 3</td><td>Benzene, 1,3 Butadiene, CO, $NO_x$ $PM_{10}$, $SO_2$, VOCs</td><td>kg/km</td></tr>
<tr><td>Light Goods Vehicles – Petrol, Diesel and LPG</td><td>Table 4</td><td>Benzene, 1,3 Butadiene, CO, $NO_x$ $PM_{10}$, $SO_2$, VOCs</td><td>kg/km</td></tr>
<tr><td>Heavy Goods Vehicles, Buses and Motorcycles</td><td>Table 5</td><td>Benzene, 1,3 Butadiene, CO, $NO_x$ $PM_{10}$, $SO_2$, VOCs</td><td>kg/km</td></tr>
<tr><td rowspan="8">Industrial</td><td>Diesel</td><td>Table 6</td><td>CO, Formaldehyde, $NO_x$, $PM_{10}$, $SO_2$, VOCs</td><td>kg/kWh</td></tr>
<tr><td>Diesel (based on fuel use)</td><td>Table 7</td><td>CO, Formaldehyde, NOx, $PM_{10}$, $SO_2$, VOCs</td><td>kg/litre</td></tr>
<tr><td>LPG</td><td>Table 8</td><td>CO, Formaldehyde, $NO_x$, $PM_{10}$, $SO_2$, VOCs</td><td>kg/kWh & kg/kg LPG</td></tr>
<tr><td>Petrol – engine</td><td>Table 9</td><td>CO, Formaldehyde, $NO_x$, $PM_{10}$, $SO_2$, VOCs</td><td>kg/kWh</td></tr>
<tr><td>Petrol (based on fuel use)</td><td>Table 10</td><td>CO, Formaldehyde, $NO_x$, $PM_{10}$, $SO_2$, VOCs</td><td>kg/litre</td></tr>
<tr><td>Petrol – Evaporative and Crankcase</td><td>Table 11</td><td>VOCs</td><td>kg/h</td></tr>
<tr><td>Load Factors</td><td>Table 12</td><td></td><td></td></tr>
</table>

| Engine/Fuel | | | Table | Pollutants | Units |
|---|---|---|---|---|---|
| Stationary Engines | Liquid Fuels | Petrol and Diesel (<450kW) – uncontrolled | Table 13 | CO, $NO_x$, $PM_{10}$, $SO_2$, VOCs | kg/kWh<br>$kg/m^3$ |
| | | Diesel (<450kW) – uncontrolled | Table 14 | Acetaldehyde, Benzene, 1,3-Butadiene, Formaldehyde, Total PAHs, Toluene, Xylenes | $kg/m^3$ |
| | | Diesel (>450kW) | Table 15 | CO, $NO_x$, $PM_{10}$, $SO_2$, VOCs | kg/kWh<br>$kg/m^3$ |
| | | Diesel (>450kW) | Table 16 | Acetaldehyde, Benzene, Formaldehyde, Toluene, Xylenes | $kg/m^3$ |
| | Diesel and Natural Gas - Dual Fuel (>450 kW) | | Table 15 | CO, $NO_x$, $PM_{10}$, $SO_2$, VOCs | $kg/m^3$ |
| | Natural Gas | ***Uncontrolled Engines*** | | | |
| | | Gas Turbines | Table 17 | Benzene, CO, Ethylbenzene, $NO_x$, VOCs, Toluene, Xylenes | kg/kWh<br>$kg/m^3$ |
| | | 2-Stroke Lean Burn | Table 18 | Acetaldehyde, Benzene, 1,3-Butadiene, Chloroform, CO (<90% Load), CO (90-105% Load), 1,2-Dichloroethane, Ethylbenzene, Formaldehyde, n-Hexane, Methanol, NOx (<90% Load), NOx (90-105% Load), PAHs, Phenol, $PM_{10}$, $SO_2$, Styrene, Toluene, Vinyl Chloride, VOCs, Xylene | $kg/m^3$ |
| | | 4-Stroke Lean Burn | Table 19 | Acetaldehyde, Benzene, Biphenyl, 1,3-Butadiene, Chloroethane, Chloroform, CO (<90% Load), CO (90-105% Load), 1,2-Dichloroethane, Ethylbenzene, Formaldehyde, Methanol, NOx (<90% Load), NOx (90-105% Load), PAHs, $PM_{10}$, $SO_2$, Styrene, Toluene, Vinyl Chloride, VOCs, Xylene, | $kg/m^3$ |
| | | 4-Stroke Rich Burn | Table 20 | Acetaldehyde, Benzene, 1,3-Butadiene, Chloroform, CO (<90% Load), CO (90-105% Load), 1,2-Dichloroethane, Ethylbenzene, Formaldehyde, Methanol, NOx (<90% Load), NOx (90-105% Load), PAHs, $PM_{10}$, $SO_2$, Styrene, Toluene, Vinyl Chloride, VOCs, Xylene, | kg/kWh<br>$kg/m^3$ |
| | | ***Controlled Engines*** | | | |
| | | 2-Stroke Lean Burn *(Increased Air/Fuel Ratio with Intercooling)* | Table 21 | CO, $NO_x$, $PM_{10}$, VOCs | kg/kWh<br>$kg/m^3$ |
| | | 2-Stroke Lean Burn *(Clean Burn)* | Table 22 | CO, $NO_x$, VOCs | kg/kWh<br>$kg/m^3$ |
| | | 2-Stroke Lean Burn *(Pre-Combustion Chamber)* | Table 23 | Ammonia, CO, $NO_x$, VOCs | kg/kWh<br>$kg/m^3$ |
| | | 4-Stroke Lean Burn *(Selective Catalytic Reduction)* | Table 24 | Acetaldehyde, Ammonia, Benzene, 1,3-Butadiene, CO, Formaldehyde, NOx, PAHs, $PM_{10}$, VOCs, Toluene, Xylenes | kg/kWh<br>$kg/m^3$ |

### 3.4.1 Emission Estimates for Combustion Engine Powered Vehicles

This section provides EETs and details the data inputs required for estimating emissions from combustion engine powered vehicles. Under the NPI, occupiers of facilities are required to report emissions from vehicles used on-site irrespective of whether they are registered. An example of on-is used both on-site and off-site, only the on-site emissions are estimated and reported to the NPI by the facility.

The EETs for vehicles provide methods for estimating emissions of CO, NOx, $PM_{10}$, $SO_2$, VOCs and other NPI reportable pollutants. The parameters required to estimate the pollutant emissions depend on the type of vehicle and how it is used. For the purpose of estimating emissions for the NPI, vehicles have been classified as either "road-transport vehicles" or "industrial vehicles". Road-transport vehicles include cars, light and heavy goods vehicles, buses and motorcycles used on either sealed roads or on well-formed unsealed roads. Emissions are estimated for these based on the distance travelled.

Industrial vehicles include heavy earth moving and construction equipment and a range of miscellaneous vehicles such as forklifts and mobile airport equipment. Industrial vehicles also include road-transport vehicles, such as cars and goods vehicles, when used on rough terrain, steep grades or poorly graded tracks. Emissions for industrial vehicles can be estimated using two different techniques. The first technique is based in engine power (Equation 4) and requires the following three factors to be known:

- the engine power in kW;
- the number of hours the engine was operated; and
- the load factor (the average engine power in use divided by the rated engine power).

The second technique is based on fuel use (Equation 6) and requires the following two factors to be know:

- the fuel use in litres (or kg for LPG vehicles); and
- the load factor (the average engine power in use divided by the rated engine power).

In some cases a vehicle, such as a light goods vehicle, may operate in both road-transport and industrial vehicle modes. If the vehicle is used predominantly in one mode then estimate emissions using the emission factors for this mode. If vehicle use is more evenly split between the two modes then both sets of conditions should be considered in estimating emissions.

For purposes of the NPI, common vehicles used in Australian industry such as the Toyota Landcruiser and Nissan Patrol are classed as Light Goods Vehicles (LGV). Small four-wheel drive vehicles are classed as cars. Further details on vehicle classification are in Appendix 4.

A number of industrial vehicles are classified under "miscellaneous". These include forklifts, airport vehicles for transporting baggage and airport vehicles (equipment tugs) for towing aeroplanes and other heavy equipment. Stationary engines at airports such as air start units, cargo loaders and ground power units are not covered in this section. For these, use the various stationary engine emission factors from Table 13 to Table 24 depending on the characteristics of the engine.

Large shovels used mainly in open-cut mining facilities to load haul trucks are classed as stationary engines as they do not move large distances and the main use of the engine within the shovel is to operate the shovel itself.

### 3.4.2 Road-transport vehicles

For road-transport vehicle pollutant emission estimations the vehicle type and distance travelled by the vehicle are required inputs to estimate pollutant emissions.

$$E_{kpy,i} = L_Y * EF_i \qquad \text{Equation 3}$$

where:

$E_{kpy,i}$ = emission of pollutant i for a specific type of engine, kg/yr
$L_Y$ = distance travelled in reporting year, km/yr
$EF_i$ = emission factor for pollutant i, for given engine and fuel type, kg/km
i = pollutant type

The distance, $L_Y$, a vehicle travels during the reporting year is determined from the vehicle odometer reading at the end of the reporting period less the odometer reading at the start of the reporting period. This data can be attained from vehicle log-books or maintenance records.

Table 3 contains the emission factors for cars, a category of road-transport vehicles, with petrol, diesel and LPG engines. The emission factors are all in terms of kg/km. As previously stated, only the on-site component of vehicle usage need be considered.

**Table 3 Emission factors for Road-Transport vehicles - Cars**

| Pollutant | Petrol (kg/km) | Diesel (kg/km) | LPG[5](kg/km) |
|---|---|---|---|
| Benzene | 3.78E-05 | 1.12E-06 | neg.[6] |
| 1,3 Butadiene | 1.07E-05 | 3.02E-06 | neg.[6] |
| CO | 5.55E-03 | 3.52E-04 | 6.16E-03 |
| $NO_x$ | 9.02E-04 | 3.43E-04 | 6.00E-04 |
| $PM_{10}$ | 1.80E-05 | 6.19E-05 | neg.[6] |
| $SO_2$ | 4.05E-05 | 3.63E-05 | neg.[6] |
| VOCs | 6.76E-04 | 5.87E-05 | 7.22E-04 |

Notes
1. Source: Reference 11 for petrol and diesel emission factors.
2. Assume an even distribution between rural and urban driving conditions.
3. Assume no freeway conditions included and one cold-start every 30km.
4. 1999 data from Reference 11 is used.
5. Based on emissions for petrol and LPG passenger vehicles. Source Reference 12 Table 5.20.
6. Source: Reference 13.
7. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors for miscellaneous industrial vehicles.
8. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

Table 4 contains emission factors for the Light Goods Vehicle category of road-transport vehicles.

**Table 4 Emission Factors for Road-Transport Vehicles – Light Goods Vehicles (LGV)**

| Pollutant | Petrol[3] (kg/km) | Diesel[3] (kg/km) | LPG[7] (kg/km) |
|---|---|---|---|
| Benzene | 5.17E-05 | 4.19E-06 | neg.[6] |
| 1,3 Butadiene | 1.78E-05 | 5.31E-06 | neg.[6] |
| CO | 1.18E-02 | 7.78E-04 | 1.32E-02 |
| $NO_x$ | 1.50E-03 | 6.36E-04 | 9.95E-04 |
| $PM_{10}$ | 3.10E-05 | 1.93E-04 | neg.[6] |
| $SO_2$ | 5.58E-05 | 6.70E-05 | neg.[6] |
| VOCs | 1.16E-03 | 2.08E-04 | 1.24E-03 |

Notes
1. Source: Reference 11 for petrol and diesel emission factors.
2. Assume an even distribution between rural and urban driving conditions.
3. Assume no freeway conditions included and one cold-start every 30km.
4. 1999 data from Reference 11 is used.
5. Based on emissions for petrol and LPG passenger vehicles. Source Reference 12 Table 5.20.
6. Source: Reference 13.
7. LGV is Light Goods Vehicle – includes large 4 wheel drive vehicles such as the Toyota Landcruiser and Nissan Patrol see appendix 4 for more details.
8. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors for miscellaneous industrial vehicles.
9. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

Table 5 contains emission factors for the Heavy Goods Vehicle (HGV), bus and motorcycle categories of road-transport vehicles.

**Table 5 Emission Factors for Road-Transport Vehicles – Diesel Heavy Goods Vehicles (HGV), Diesel Buses and Petrol Motorcycles.**

| Pollutant | Rigid HGV[5] (kg/km) | Articulated HGV[5] (kg/km) | Buses (kg/km) | Motorcycles (kg/km) |
|---|---|---|---|---|
| Benzene | 4.11E-05 | 2.95E-05 | 3.62E-05 | 3.79E-05 |
| 1,3 Butadiene | 1.26E-05 | 1.94E-05 | 1.31E-05 | 1.48E-05 |
| CO | 2.51E-03 | 2.32E-03 | 5.06E-03 | 1.90E-02 |
| $NO_x$ | 6.38E-03 | 1.19E-02 | 1.00E-02 | 1.20E-04 |
| $PM_{10}$ | 4.94E-04 | 5.06E-04 | 5.69E-04 | 8.70E-05 |
| $SO_2$ | 1.72E-04 | 3.56E-04 | 2.65E-04 | 2.40E-05 |
| VOCs | 2.05E-03 | 1.47E-03 | 1.81E-03 | 5.01E-03 |

Notes
1. Source: Reference 11 for petrol and diesel emission factors.
2. Assume an even distribution between rural and urban driving conditions.
3. Assume no freeway conditions included and one cold-start every 30km.
4. 1999 data from Reference 11 is used.
5. HGV is Heavy Goods Vehicle.
6. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors for miscellaneous industrial vehicles.
7. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

### 3.4.3 Industrial Vehicles

To estimate emissions from industrial vehicles the following data is required:

- emission factors;
- engine power or fuel use;
- load factor; and
- if the engine power basis is used the hours of use in the reporting year.

Equation 4 estimates emissions for individual industrial vehicles based on engine power using the emission factors in Table 6, Table 8 and Table 9 and the load factors in Table 12.

$$E_{kpy,i} = P * OpHrs * LF * EF_i \qquad \text{Equation 4}$$

where:

$E_{kpy,i}$ = emission of pollutant i for a specific type of engine, kg/yr
P = average rated engine power, kW
OpHrs = vehicle operating hours, h/yr
LF = load factor utilised in facility operations for equipment type (see Table 12)
$EF_i$ = emission factor for pollutant i, for given engine and fuel type, kg/kWh
i = pollutant type

The engine power (P) is an engine specification provided by the engine manufacturer. A common unit for engine power, especially for engines from the US, is horsepower (hp). The conversion factor of 1 hp = 0.7456 kW is used to convert hp to kW. Other useful conversion factors are in Appendix 1 and further conversion factors can be obtained from many sources, e.g. Reference 8.

The best method of obtaining vehicle-operating hours (OpHrs) is to use a logbook to log the hours of operation at the end of every day or shift. A less accurate alternative is an estimate based on distance travelled as outlined in 3.4.2. Another less accurate method is based on estimated hours over a period of time and extrapolating this to estimate the operating hours for the reporting year.

The load factor (LF) term is used to allow for the variation in operation that is typical of vehicles. For example, since it is impossible to drive a car continuously at full engine power a LF of 0.25 is used for cars and utilities used in rough terrain. If the vehicle for which you are estimating the pollutant emissions is not specifically in Table 12, use the LF for equipment that is similar or use the default LF of 0.5.

For petrol powered industrial vehicles VOCs emissions occur from exhaust and also from evaporation and the crankcase. The evaporative and crankcase VOCs emissions are dependent only on the hours of operation as in Equation 5. Emission factors (in kg/h) for Equation 5 are in Table 11.

$$E_{kpy,i} = OpHrs * EF_i \qquad \text{Equation 5}$$

where:

$E_{kpy,i}$ = emission of pollutant i for a specific type of engine, kg/yr
OpHrs = vehicle operating hours, h/yr
$EF_i$ = emission factor for pollutant i, for given engine and fuel type, kg/h
i = pollutant type

Equation 6 estimates emissions for individual industrial vehicles based on fuel consumption using the emission factors from Table 7, Table 8 and Table 10 and the load factors in Table 12

$$E_{kpy,i} = F * LF * EF_i \qquad \text{Equation 6}$$

where:

$E_{kpy,i}$ = emission of pollutant i for a specific type of engine, kg/yr
F = vehicle fuel use, kg or litres per year
LF = load factor utilised in facility operations for equipment type (see Table 12)
$EF_i$ = emission factor for pollutant i, for given engine and fuel type, kg/litre or kg (kg for LPG in Table 8 and litres for liquid fuels in Table 7 and Table 10)
i = pollutant type

The total VOCs emissions are obtained from summing exhaust VOCs emissions derived from Equation 4 or Equation 6 and evaporative and crankcase emissions derived from Equation 5.

**Table 6 Emission Factors for Diesel Industrial Vehicle Exhaust Emissions (based on engine power)**

| Pollutant | Track-type tractor (kg/kWh) | Wheeled tractor (kg/kWh) | Wheeled dozer (kg/kWh) | Scraper (kg/kWh) | Motor grader (kg/kWh) |
|---|---|---|---|---|---|
| CO | 2.88E-03 | 9.84E-03 | 4.70E-03 | 3.28E-03 | 2.06E-03 |
| Formaldehyde | 2.28E-04 | 3.78E-04 | 2.15E-04 | 3.75E-04 | 1.62E-04 |
| $NO_x$ | 1.05E-02 | 1.60E-02 | 1.09E-02 | 1.00E-02 | 9.57E-03 |
| $PM_{10}$ | 9.28E-04 | 1.70E-03 | 5.51E-04 | 1.06E-03 | 8.38E-04 |
| $SO_2$ | 1.14E-03 | 1.14E-03 | 1.16E-03 | 1.21E-03 | 1.17E-03 |
| VOCs | 1.01E-03 | 2.36E-03 | 5.00E-04 | 7.40E-04 | 4.80E-04 |
| **Pollutant** | **Wheeled loader (kg/kWh)** | **Track-type loader (kg/kWh)** | **Off-Highway truck (kg/kWh)** | **Roller (kg/kWh)** | **Miscellaneous (kg/kWh)** |
| CO | 3.63E-03 | 3.03E-03 | 4.70E-03 | 8.08E-03 | 6.16E-03 |
| Formaldehyde | 2.64E-04 | 1.34E-04 | 2.95E-04 | 2.63E-04 | 2.72E-04 |
| $NO_x$ | 1.18E-02 | 1.25E-02 | 1.09E-02 | 1.75E-02 | 1.48E-02 |
| $PM_{10}$ | 1.08E-03 | 8.78E-04 | 6.73E-04 | 1.04E-03 | 1.21E-03 |
| $SO_2$ | 1.15E-03 | 1.14E-03 | 1.19E-03 | 1.34E-03 | 1.25E-03 |
| VOCs | 1.59E-03 | 1.49E-03 | 5.00E-04 | 1.30E-03 | 1.35E-03 |

Notes
1. Source: Reference 10, Table II-7.1.
2. Scientific notation is used; e.g. 7.38E-02 represents 7.38 x $10^{-2}$ or 0.0738.

**Table 7 Emission Factors for Diesel Industrial Vehicle Exhaust Emissions (based on fuel use)**

| Pollutant | Track-type tractor (kg/litre) | Wheeled tractor (kg/ litre) | Wheeled dozer (kg/ litre) | Scraper (kg/ litre) | Motor grader (kg/ litre) |
|---|---|---|---|---|---|
| CO | 9.40E-03 | 3.22E-02 | 1.47E-02 | 1.02E-02 | 6.55E-03 |
| Formaldehyde | 7.45E-04 | 1.23E-03 | 6.90E-04 | 1.16E-03 | 5.17E-04 |
| $NO_x$ | 3.42E-02 | 5.24E-02 | 3.43E-02 | 3.10E-02 | 3.04E-02 |
| $PM_{10}$ | 3.03E-03 | 5.57E-03 | 1.77E-03 | 3.27E-03 | 2.66E-03 |
| $SO_2$ | 3.73E-03 | 3.73E-03 | 3.74E-03 | 3.74E-03 | 3.73E-03 |
| VOCs | 3.31E-03 | 7.74E-03 | 1.58E-03 | 2.28E-03 | 1.53E-03 |
| **Pollutant** | **Wheeled loader (kg/ litre)** | **Track-type loader (kg/ litre)** | **Off-Highway truck (kg/ litre)** | **Roller (kg/ litre)** | **Miscellaneous (kg/ litre)** |
| CO | 1.18E-02 | 9.93E-03 | 1.47E-02 | 2.26E-02 | 1.84E-02 |
| Formaldehyde | 8.59E-04 | 4.39E-04 | 9028E-04 | 7.31E-04 | 8.13E-04 |
| $NO_x$ | 3.85E-02 | 4.08E-02 | 3.43E-02 | 4.85E-02 | 4.41E-02 |
| $PM_{10}$ | 3.51E-03 | 2.88E-03 | 2.12E-03 | 2.90E-03 | 3.61E-03 |
| $SO_2$ | 3.74E-03 | 3.74E-03 | 3.74E-03 | 3.73E-03 | 3.73E-03 |
| VOCs | 5.17E-03 | 4.85E-03 | 1.58E-03 | 3.60E-03 | 4.04E-03 |

Notes
1. Source: Reference 10, Table II-7.1.
2. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 8 Emission factors for Miscellaneous LPG Industrial Vehicle Exhaust Emissions (based on engine power or fuel use)**

| Pollutant | LPG (kg/kWh) Miscellaneous[2] | LPG (kg/kg LPG) Miscellaneous[2, 4] |
|---|---|---|
| CO | 8.62E-02[5] | 3.00E-01[5] |
| Formaldehyde | neg.[3] | neg.[3] |
| $NO_x$ | 4.31E-03 | 1.50E-02 |
| $PM_{10}$ | neg.[3] | neg.[3] |
| $SO_2$ | neg.[3] | neg.[3] |
| VOCs | 9.29E-03 | 3.27E-02 |

Notes
1. Source: Reference 10, Table II-7.1.
2. Based on emissions for petrol and LPG passenger cars. Source: Reference 12 Table 5.20.
3. Source: Reference 13.
4. Assumes fuel consumption is the same as for petrol on a mass basis.
5. Based on the average $CO/CO_2$ ratio from passenger vehicle CO emission tests. Source: Reference 15.
6. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 9 Emission Factors for Petrol Industrial Vehicle Exhaust Emissions (based on engine power)**

| Pollutant | Wheeled tractor (kg/kWh) | Motor grader (kg/kWh) | Wheeled loader (kg/kWh) | Roller (kg/kWh) | Miscellaneous (kg/kWh) |
|---|---|---|---|---|---|
| CO | 1.90E-01 | 2.51E-01 | 2.19E-01 | 2.71E-01 | 2.66E-01 |
| Formaldehyde | 3.41E-04 | 3.86E-04 | 2.98E-04 | 3.43E-04 | 2.98E-04 |
| $NO_x$ | 8.54E-03 | 6.57E-03 | 7.27E-03 | 7.08E-03 | 6.48E-03 |
| $PM_{10}$ | 4.84E-04 | 4.40E-04 | 4.21E-04 | 5.27E-04 | 4.06E-04 |
| $SO_2$ | 3.04E-04 | 3.41E-04 | 3.19E-04 | 3.73E-04 | 3.54E-04 |
| VOCs | 7.16E-03 | 8.48E-03 | 7.46E-03 | 1.24E-02 | 8.70E-03 |

Notes
1. Source: Reference 10, Table II-7.2.
2. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 10 Emission Factors for Petrol Industrial Vehicle Exhaust Emissions (based on fuel use)**

| Pollutant | Wheeled tractor (kg/litre) | Motor grader (kg/ litre) | Wheeled loader (kg/ litre) | Roller (kg/ litre) | Miscellaneous (kg/ litre) |
|---|---|---|---|---|---|
| CO | 3.89E-01 | 4.69E-01 | 4.35E-01 | 4.60E-01 | 4.75E-01 |
| Formaldehyde | 6.97E-04 | 7.21E-04 | 5.93E-04 | 5.82E-04 | 5.32E-04 |
| $NO_x$ | 1.75E-02 | 1.22E-02 | 1.45E-02 | 1.20E-02 | 1.15E-02 |
| $PM_{10}$ | 9.91E-04 | 8.22E-04 | 8.39E-04 | 8.95E-04 | 7.26E-04 |
| $SO_2$ | 6.23E-04 | 6.36E-04 | 6.36E-04 | 6.33E-04 | 6.33E-04 |
| VOCs | 1.46E-02 | 1.58E-02 | 1.49E-02 | 2.11E-02 | 1.56E-02 |

Notes
1. Source: Reference 10, Table II-7.2.
2. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 11 Emission factors for Petrol Industrial Vehicle Evaporative and Crankcase Emissions**

| Pollutant | Wheeled tractor (kg/h) | Motor grader (kg/h) | Wheeled loader (kg/h) | Roller (kg/h) | Miscellaneous (kg/h) |
|---|---|---|---|---|---|
| Evaporative VOCs | 3.09E-02 | 3.00E-02 | 2.97E-02 | 2.82E-02 | 2.54E-02 |
| Crankcase VOCs | 3.26E-02 | 3.71E-02 | 4.82E-02 | 5.55E-02 | 5.07E-02 |

Notes
1. Source: Reference 10, Table II-7.2.
2. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 12 Load Factors for Various "Miscellaneous" Industrial Vehicles**

| Industrial vehicle type | Load factor |
|---|---|
| Car[1] | 0.25 |
| Bus[1] | 0.25 |
| Utility[1] | 0.25 |
| LGV[1] | 0.25 |
| HGV[1] | 0.25 |
| Forklift | 0.20 |
| Airport equipment tug | 0.80 |
| Airport baggage tugs | 0.55 |
| Track-type tractor | 0.55 |
| Wheeled tractor | 0.55 |
| Wheeled dozer | 0.55 |
| Scraper | 0.50 |
| Motor grader | 0.50 |
| Wheeled loader | 0.50 |
| Track-type loader | 0.50 |
| Off-highway truck | 0.50 |
| Roller | 0.50 |

Note:
1. Used on rough terrain, steep grades or poorly graded tracks

***Steps for Estimating Vehicle Emissions***

The five steps to estimate the quantity of pollutants emitted from combustion engine powered vehicles are given below and also outlined in the worksheet in Appendix 2:

***Step 1***

Determine if vehicle is used under road-transport or industrial vehicle conditions.

The conditions under which a vehicle is used are those under which it is used the greatest length of time during the reporting year. Occasionally both conditions have to be accounted for.

***Step 2***

Determine vehicle engine power (P) in kW, or fuel use (F) in litres or kg per year and load factor (LF).

The engine power can be obtained from the owner's/operating manual or manufacturer. If the power is known in horsepower it can be converted to kW using 1hp = 0.7456 kW. Other conversion factors are provided in Appendix 1.

The load factor is obtained from Table 12. If the vehicle is mainly used under road-transport - conditions then step 2 is not required.

***Step 3***
Determine operation hours for the reporting year (OpHrs) for estimates based on engine power.

Vehicle operating hours may be available from vehicle logbooks or plant log sheets. An estimation of operating hours can be obtained from the kilometres travelled for a certain number of operating hours for a period of typical vehicle usage using 3.4.4 and the worksheet in Appendix 3.

If the vehicle is mainly used under road-transport conditions or using the fuel use technique for industrial vehicles, then step 3 is not required.

***Step 4***
Determine road-transport vehicle distance travelled ($L_Y$).

The distance a vehicle travels during the reporting year, $L_Y$, can be determined from the vehicle odometer reading at the end of the reporting period less the odometer reading at the start of the reporting period. This data can be attained from vehicle log-books or maintenance records.

If the vehicle is mainly used under industrial-transport conditions then step 4 is not required.

***Step 5***
Select the appropriate emission factor ($EF_i$) values for vehicles and calculate emissions. Ensure that evaporative and crankcase emissions from Table 11 are included if appropriate.

The emission factor values depend on the type of engine and the mode of vehicle use. The emission factors for industrial vehicles are based on hours of engine operation and emission factors for road-transport vehicles use are based on distance travelled. For vehicles that have significant usage in both modes an estimate of the most prevalent mode is used to determine emissions. See Example 3 for an example of this technique.

For petrol industrial vehicles ensure that the evaporative and crankcase VOCs emissions are included as part of the total VOCs emissions from the vehicle. The VOCs emissions from evaporation and crankcase sources depends only on the hours of operation and not the engine power and load factor as for the other industrial vehicle emissions.

Calculate emissions using appropriate equations.

### 3.4.4 Estimating Industrial Vehicle Operating Hours Using Distance Travelled

To determine industrial vehicle emissions using engine power emission factors in this Manual, the vehicle operating hours are required. As already outlined, this can be obtained from various sources such as plant or vehicle logs. Alternatively, the operating hours can be estimated from Equation 7 using a typical period of operation to estimate the operating hours for the reporting year. The information required is the distance the vehicle travels in the reporting year, and for a typical period for which the operating hours are recorded accurately, e.g. four weeks.

$$OpHrs = OpHrs_P * \left( L_Y / L_P \right) \qquad \text{Equation 7}$$

where:

| | | |
|---|---|---|
| OpHrs | = | operating hours for vehicle reporitn year, h.yr |
| $OpHrs_P$ | = | operating hours for vehicle for typical period of operation of at least 4 weeks, h/period |
| $L_Y$ | = | distance travelled in reporting year, km/yr |
| $L_P$ | = | distance travelled for typical period of operation, km/period |

Appendix 3 contains a worksheet to complete this calculation and outlines the steps involved.

Example 2 illustrates the application of Equation 3 using a load factor from Table 12 and emission factors from Table 9 and Table 11. All data inputs are described.

***Example 2 - Calculating Petrol and Diesel Engine Vehicle Emissions***

For this example, emissions are estimated for an wheeled tractor (industrial vehicle) with a 78 hp petrol engine used for 1 021 hours during the reporting year.

***Step 1***

Determine if vehicle is used under road-transport or industrial vehicle conditions.

The tractor is used under industrial conditions.

***Step 2***

Determine vehicle engine power (P) in kW, or fuel use (F) in litres of kg per year and load factor (LF).

i) The engine power is given as 78 hp. $78\text{hp} = 78\text{hp} * \frac{0.7456\text{kW}}{\text{hp}} = 58\text{kW}$

ii) From Table 12 the load factor for a tractor is 0.55.

***Step 3***

Determine operation hours for the reporting year (OpHrs) for estimates based on engine power.

The operating hours of the vehicle for the reporting year are stated as 1021 hours under industrial vehicle conditions.

***Step 4***

Determine road-transport vehicle distance travelled ($L_Y$).

The tractor is not a road-transport vehicle so this step is not required.

***Step 5***

Select the appropriate EF values for vehicles and calculate emissions.

As the vehicle is a petrol industrial vehicle Table 9 engine emission factors and evaporative/crankcase emission factors from Table 11 are used. From the vehicle type emission factors are read from the left column of Table 9 and are below. The reportable emissions are in the right column in step 5 below.

***Example 2 - Calculating Petrol and Diesel Engine Vehicle Emissions (cont.)***

Emission are calculated below using Equation 4.

| Pollutant | Power | | Operating Hours | | Emission Factor | | Load Factor | | = | Emissions |
|---|---|---|---|---|---|---|---|---|---|---|
| i | (kW) | | (h/yr) | | (kg/kWh) | | | | = | (kg/yr) |
| | P | * | OpHrs | * | $EF_I$ | * | LF | | = | $E_{kpy,i}$ |
| CO | 58 | * | 1 021 | * | 1.90E-01 | * | 0.55 | | = | 6.19E+03 |
| Formaldehyde | 58 | * | 1 021 | * | 3.41E-04 | * | 0.55 | | = | 1.11E+01 |
| $NO_x$ | 58 | * | 1 021 | * | 8.54E-03 | * | 0.55 | | = | 2.78E+02 |
| $PM_{10}$ | 58 | * | 1 021 | * | 4.84E-04 | * | 0.55 | | = | 1.58E+01 |
| $SO_2$ | 58 | * | 1 021 | * | 3.04E-04 | * | 0.55 | | = | 9.90E+00 |
| VOCs - engine | 58 | * | 1 021 | * | 7.16E-03 | * | 0.55 | = 2.33E+02 | | |
| VOCs - evaporative | | | 1 021 | * | 3.09E-02 | | | = 3.15E+01 | | |
| VOCs - crankcase | | | 1 021 | * | 3.26E-02 | | | = 3.33E+01 | | |
| VOCs - total | | | | | | | | 2.98E+02 | = | 2.98E+02 |

Note: VOCs is the sum of engine, crankcase and evaporative emissions.

Example 3 shows typical usage of a common utility/light truck used as a road-transport vehicle and industrial vehicle during the NPI reporting year.

***Example 3 - Estimating Emissions from a Utility with a Diesel Engine***

An on-site diesel utility/light truck with a 100 kW engine completed 10,000 km in the NPI reporting year, of which 25% was under industrial vehicle conditions on steep poorly graded terrain and 75% under road-transport conditions. An example of this type of vehicle is a Toyota Landcruiser or Nissan Patrol.

***Step 1***

Determine if vehicle is used under road-transport or industrial vehicle conditions.

The vehicle is used under mostly road-transport conditions so road-transport emission factors and techniques will be used to estimate the vehicle's pollutant emissions.

***Step 2***

Determine vehicle engine power (P) in kW and load factor (LF) if used under industrial vehicle conditions.

As the vehicle is designated road-transport usage this step is not required.

***Step 3***

Determine industrial vehicle operation hours for the reporting year.

As the vehicle is designated road-transport usage this step is not required.

***Step 4***

Determine road-transport distance travelled ($L_Y$).

The vehicle travels 10,000 km in the reporting year.

***Step 5***

Select the appropriate EF values for vehicles and calculate emissions. The emission factors are those for a diesel Light Goods Vehicle (LGV) from the second column of emission factors from Table 4.

Emissions for the vehicle from Equation 3 are:

| | Distance | | Emission Factor (diesel LGV) | = | Emissions |
|---|---|---|---|---|---|
| i | (km) | | (kg/km) | = | (kg/yr) |
| | $L_Y$* EF | | | = | $E_{kpy,i}$ |
| Benzene | 10,000 | * | 4.19E-06 | = | 4.19E-02 |
| 1,3 Butadiene | 10,000 | * | 5.31E-06 | = | 5.31E-02 |
| CO | 10,000 | * | 7.78E-04 | = | 7.78E+00 |
| NOx | 10,000 | * | 6.36E-04 | = | 6.36E+00 |
| $PM_{10}$ | 10,000 | * | 1.93E-04 | = | 1.93E+00 |
| $SO_2$ | 10,000 | * | 6.70E-05 | = | 6.70E-01 |
| VOCs | 10,000 | * | 2.08E-04 | = | 2.08E+00 |

### 3.4.5 Emission Estimates from Stationary Combustion Engines

Estimating emissions of CO, $NO_x$, $PM_{10}$, $SO_2$ and VOCs and other NPI substances from stationary combustion engines can be undertaken using emission factors based either on the engine power and operating hours or on the quantity of fuel input for the reporting year. For some specific engine categories, for pollutants other than CO, $NO_x$, $PM_{10}$, $SO_2$ and VOCs, emissions have to be estimated with the fuel-input technique.

The emission factors for stationary engines are in Table 13 to Table 24. A wide variety of engines is covered in these tables; the criteria used to differentiate the engines are usually fuel type and engine size. For a wide range of stationary combustion engine powered equipment, such as compressors and pumps, the pollutants emitted can be estimated using Table 13 to Table 16 if the engine power and fuel consumption is known. The term *uncontrolled diesel engine* refers to an engine with no pollution abatement equipment. Various types of pollution abatement equipment are described in Table 25 and their fitment can be determined by examining either the owner's manual for the engine or the engine's records.

The emission factors for natural gas powered engines are covered in Table 17 to Table 24. Large natural gas engines are used for electricity production and in the natural gas industry to compress and transport natural gas. The emission factors for natural gas engines of various types using different types of emission control techniques are in Table 21 to Table 24.

The term *reciprocating engine* is another term for internal combustion engine. In some circles reciprocating engines refer specifically to lightweight and efficient engines used for propeller driven aircraft. The term *prime mover* refers to the stationary engine that is the main supplier of force or power for a given situation; it should not be confused with the common term used in Australia where a prime mover is a large truck.

For stationary engines there is no load factor (LF) term used. Stationary engines undergo relatively little variation in power output and are usually chosen and operated in the most fuel-efficient mode at close to maximum engine output.

### 3.4.6 Engine Power Method to Estimate Pollutant Emissions from Stationary Combustion Engines

Emission factors are chosen from Table 13, Table 15, Table 17 and Table 21 to Table 24 based on engine power, fuel type and pollution control equipment fitted and, for natural gas engines, the type of engine. The technique used is similar to that described in 3.4.1 for combustion engine powered industrial vehicles, except that the second step is different: instead of LF, the emission reduction efficiency of any pollution control equipment is determined. Total pollutant emissions from a stationary combustion engine can be estimated by applying Equation 8.

$$E_{kpy,i} = P * OpHrs * EF_i * (1 - ER/100) \qquad \text{Equation 8}$$

where:

$E_{kpy,i}$ = total emission of pollutant i from the stationary combustion engine for the NPI reporting year, kg/yr

P = engine power capacity rating, kW

OpHrs = operating hours of engine during the NPI reporting year, h/yr

$EF_i$ = emission factor for pollutant i, kg/kWh

ER = emission reduction efficiency, wt%

i = pollutant

Be aware that emission reduction efficiency (ER) is not the same for all pollutants emitted from a combustion engine. Typically emission reduction focuses on $NO_x$ emissions (see Table 26) and in some cases particulate matter ($PM_{10}$).

Engine operating hours (OpHrs) is a critical aspect of estimating the pollutant emissions using this technique. The best method of obtaining engine operating hours is to use a logbook to log the hours of operation at the end of every day or shift. This can also be a useful tool for engine maintenance programs. A less accurate method is based on estimated hours over a period of time and extrapolating this to estimate the operating hours for the reporting year. The least accurate operating hours estimate is from a table of typical operating hours for that engine type.

The five steps to estimate the quantity of pollutants emitted from stationary combustion engines are as follows:

***Step 1***

Determine the power of the stationary combustion engine in kW.

This can be obtained from the owner's operating manual or manufacturer. If the power is known in horsepower in can be converted to kW using 1hp = 0.7456 kW. Other useful conversion factors are in Appendix 1.

***Step 2***

Determine the ER factors for various pollutants from the engine.

This is obtained from the engine manufacturer or pollution control equipment manufacturer or the relevant operating manual. If no emission reduction equipment is fitted to the engine the value of ER is zero. The ER for the engine may be different for the different pollutants emitted. As outlined in Section 2.2.1 and Table 26 respectively the ER often refers to $PM_{10}$ and $NO_x$ determinations only.

***Step 3***

Obtain or estimate engine operating hours for the reporting year.

Engine operating hours may be available from machine/engine logbooks or plant log sheets. If they are not logged there are various less accurate techniques of estimating the operating hours described in this manual in the current section (3.4.6).

***Step 4***

Select the appropriate EF values.

This will depend on the type of engine and can be obtained from the appropriate table between Table 13 and Table 24. Determining which table to use requires the following information: engine power (from Step 1 above, in kW), fuel-type and type of engine.

***Step 5***

Calculate emissions using Equation 8.

***Example 4 - Calculating Stationary Engine Emissions - Engine Power Technique***

This example illustrates the steps for estimating pollutant emissions from a 250 kW diesel engine used for 3650 hours during the reporting year. The engine is fitted with a pollution control device with an emission reduction efficiency of 90 wt% for $PM_{10}$ and 20 wt% for $NO_x$.

***Step 1***

Determine the engine power in kW.

The engine power is 250 kW

***Example 4 - Calculating Stationary Engine Emissions - Engine Power Technique (cont.)***

***Step 2***

Determine the ER factors for various pollutants from the engine.

It is stated the ER factor is 90 wt% for $PM_{10}$ and 20 wt% for $NO_x$.

***Step 3***

Obtain or estimate the engine operating hours for the reporting year.

3650 h, for the reporting year examined.

***Step 4***

Select the appropriate EF values from between Table 13 and Table 24.

For a diesel engine of less than 450 kW Table 13 is used to obtain the emission factors. The third data column is used.

***Step 5***

Calculate pollutant emissions using Equation 8.

| Pollutant (i) | Engine Power (kW) | | Operating Hours (hr/yr) | | Emission Factor (kg/kWh) | | Fraction Released | | Emissions (kg/yr) |
|---|---|---|---|---|---|---|---|---|---|
| | P | * | OpHrs | * | $EF_i$* | | 1 - ER/100 | = | $E_{kpy,i}$ |
| CO | 250 | * | 3 650 | * | 4.06E-03 | * | 1.0 | = | 3.70E+03 |
| $NO_x$ | 250 | * | 3 650 | * | 1.88E-02 | * | 0.8 | = | 1.37E+04 |
| $PM_{10}$ | 250 | * | 3 650 | * | 1.34 E-03 | * | 0.1 | = | 1.22E+02 |
| $SO_2$ | 250 | * | 3 650 | * | 1.25 E-03 | * | 1.0 | = | 1.14E+03 |
| VOCs | 250 | * | 3 650 | * | 1.37E-03 | * | 1.0 | = | 1.25E+03 |

### 3.4.7 Estimating Stationary Engine Operating Time

If stationary engine operating time is unknown there are several methods of estimating it based on typical periods of engine operation.

If the annual fuel consumption for an engine is known the operating hours can be estimated by determining the fuel consumption rate for a typical period of operation and extrapolating that to a year of operation.

If engine usage is regular the annual operating hours can be estimated from logging the operating hours for a typical period, for example one-month, and extrapolating that to a year of operation.

If the fuel consumed for the reporting period is known then where applicable the fuel consumption method of estimating emissions (see Section 3.4.8) is best used.

### 3.4.8 Fuel Consumption Method to Estimate Pollutant Emissions from Stationary Combustion Engines

This technique is different from the two techniques described so far, as it relies on the fuel used rather than the engine power to determine the emission levels. The information required and steps involved to complete the estimate are different. Emissions are estimated by multiplying the quantity of fuel burned ($m^3$) by the emission factor for each specific pollutant.

Total pollutant emissions from a stationary combustion engine can be estimated by applying Equation 9.

$$E_{kpy,i} = F * EF_i * (1 - ER/100) \qquad \text{Equation 9}$$

where:

| | | |
|---|---|---|
| $E_{kpy,i}$ | = | total emission of pollutant i from engine, kg/yr |
| F | = | fuel used by engine for the NPI reporting year, $m^3$ |
| $EF_i$ | = | emission factor for pollutant i, $kg/m^3$ fuel |
| ER | = | emission reduction efficiency, wt% |
| i | = | pollutant |

Be aware that emission reduction efficiency (ER) is not the same for all pollutants emitted from a combustion engine. Typically emission reduction focuses on $NO_x$ emissions (see Table 26) and in some cases particulate matter ($PM_{10}$).

The five steps to estimate the quantity of pollutants emitted from stationary combustion engines from the volume of fuel used are detailed below:

***Step 1***

Determine the fuel used during the NPI reporting year.

This can be obtained from plant records, equipment records or fuel delivery records. If the fuel used is known in litres (L) it can be converted to $m^3$ using 1 $m^3$ = 1000 L. Other conversion factors are in Appendix 1.

If the fuel consumption is known by weight the fuel density can be used to convert the consumption to volume. Fuel density information can be obtained from the fuel supplier; some typical values are listed in Table 29 in Appendix 1. Equation 10 can be used to convert fuel weight to fuel volume.

$$F = FW / Density \qquad \text{Equation 10}$$

where:

| | | |
|---|---|---|
| F | = | fuel volume used by engine for the NPI reporting year, $m^3$ |
| FW | = | fuel weight used by engine for the NPI reporting year, kg |
| Density | = | fuel density, $kg/m^3$ |

If the fuel usage is not known for a particular engine it can be estimated from the engines operating hours and typical fuel consumption for that engine as shown in Equation 11.

***Step 2***

Determine the ER factors for various pollutants from the engine.

This is obtained from the engine manufacturer, the pollution control equipment manufacturer or the operating manual. If no emission reduction equipment is fitted to the engine the value of ER is zero. The ER may be different for the different pollutants to be reported. As outlined in Section 2.2.1 and Table 26 respectively the ER often refers to $PM_{10}$ and $NO_x$ determinations only.

***Step 3***

Determine if engine power is greater than or less than 450 kW and the type of fuel.

The type of fuel used will be diesel, petrol or one of the other fuels listed in the various tables outlining the emission factors for different stationary engines, Table 13 to Table 22. The engine power is used to determine which emission factor table to use to look up emission factors, not to estimate pollutant emissions directly.

***Step 4***

Select the appropriate EF values.

These are obtained from between Table 13 and Table 24, depending on the information gathered in Step 3 above.

***Step 5***

Calculate emissions using Equation 9.

Example 5 illustrates the application of Equation 6 using the emission factors from Table 13. Other data required is detailed below.

***Example 5 - Estimating Stationary Engine Emissions Using the Fuel Input Technique***

Emissions are estimated using Equation 9 for a diesel engine of 400 kW that used 300 $m^3$ of fuel during the reporting year. The engine is fitted with a pollution control device with an emission reduction efficiency of 90 wt% for $PM_{10}$ and 80 wt% for $NO_x$.

***Step 1***

Determine the fuel quantity used in the reporting year.

The fuel used in the NPI reporting year was 300 $m^3$.

***Step 2***

Determine the ER factors for various pollutants from the engine.

It is stated the ER factor is 90 wt% for $PM_{10}$ and 80 wt% for $NO_x$.

***Step 3***

Determine if engine power is greater than or less than 450 kW and the type of fuel.

The engine is a 400kW diesel engine - less than 450 kW.

***Step 4***

Select the appropriate EF values.

From the engine specifications in Step 3 above the EF values are determined from the second last column in Table 13.

***Example 5 - Estimating Stationary Engine Emissions Using the Fuel Input Technique (cont.)***

***Step 5***
Calculate emissions using Equation 9

| Pollutant | Fuel Usage ($m^3$/yr) | | Emission Factor ($kg/m^3$) | | Fraction Released (kg/yr) | | Emissions |
|---|---|---|---|---|---|---|---|
| | F | * | $EF_I$ | * | $(1-ER_i/100)$ | = | $E_{kpy,i}$ |
| CO | 300 | * | 1.56E+01 | * | 1.0 | = | 4.68E+03 |
| $NO_x$ | 300 | * | 7.25E+01 | * | 0.2 | = | 4.35E+03 |
| $PM_{10}$ | 300 | * | 5.10E+00 | * | 0.1 | = | 1.53E+02 |
| $SO_2$ | 300 | * | 4.77E+00 | * | 1.0 | = | 1.43E+03 |
| VOCs | 300 | * | 5.30E+00 | * | 1.0 | = | 1.59E+03 |

### 3.4.9 Estimating Stationary Engine Fuel Consumption

If the fuel consumed by a stationary engine is unknown the amount of fuel used can be estimated using Equation 11.

$$F = F_P * \left( OpHrs_Y / OpHrs_P \right)$$ Equation 11

where:

| | | |
|---|---|---|
| F | = | fuel used for reporting year, $m^3$/yr |
| $F_P$ | = | fuel used for typical period of engine operation, $m^3$ |
| $OpHrs_Y$ | = | engine operating hours for reporting year, h/yr |
| $OpHrs_P$ | = | time of typical period of engine operation, h |

If all the stationary combustion engines at an operation are in the same category based on their size, type and emission reduction equipment then the fuel consumption method for estimating the emissions from stationary combustion engines can be used based on the total amount of fuel used for the site. This means the appropriate emission factors are obtained from the same column of the same table for all engines on the site.

Air pollution control methods for combustion engines include steam injection, water injection, and selective catalytic reduction for $NO_x$ control. Table 25 and Table 26 provide further detail of the emission reduction equipment and emission control technologies available for combustion engines.

Table 13 to Table 16 provide emission factors for small (less than 450 kW) and large (greater than or equal to 450 kW) stationary diesel engines. The emission factors for small engines, for example small diesel water pumps, are in Table 13 and Table 14. The emission factors for large engines, for example large air compressors or draglines, are in Table 15 and Table 16. Table 13 and Table 15 contain the emission factors for the main pollutants; VOCs, CO, $NO_x$, $PM_{10}$ and $SO_2$. Table 14 and Table 16 contain the emission factors for other important notifiable pollutants; Benzene, Toluene, Xylenes, Acetaldehyde and Formaldehyde. Table 15 also includes the emission factors for natural gas and diesel dual fuel engines, which are typically used in the natural gas industry.

**Table 13 Emission Factors (kg/kWh & kg/m³) for Stationary Uncontrolled Petrol and Diesel Engines (Less than 450kW)**

| Pollutant | Petrol | | Diesel | | Emission Factor Rating[4] |
|---|---|---|---|---|---|
| | Emission Factor Based on: | | Emission Factor Based on: | | |
| | Power Output (kg/kWh) | Fuel Input $(kg/m^3)^5$ | Power Output (kg/kWh) | Fuel Input $(kg/m^3)^5$ | |
| CO | 2.67E-01 | 9.27E+02 | 4.06E-03 | 1.56E+01 | D |
| $NO_x$ | 6.69E-03 | 2.41E+01 | 1.88E-02 | 7.25E+01 | D |
| $PM_{10}$ | 4.38E-04 | 1.48E+00 | 1.34E-03 | 5.10E+00 | D |
| $SO_2$ | 3.59E-04 | 1.24E+00 | 1.25E-03 | 4.77E+00 | D |
| VOCs[3] | 1.18E-02 | 4.01E+01 | 1.37E-03 | 5.30E+00 | E |
| VOCs consist of: | | | | | |
| Crankcase | 2.64E-03 | 9.14E+00 | 2.40E-05 | 1.47E-01 | E |
| Evaporative | 3.60E-04 | 1.19E+00 | neg. | neg. | E |
| Exhaust | 8.17E-03 | 2.78E+01 | 1.34E-03 | 5.15E+00 | D |
| Refuelling | 5.88E-04 | 1.99E+00 | neg. | neg. | E |

Notes:
1. Source: Reference 5, Table 3.3-1.
2. When necessary in the source data (reference above) Fuel Input EF was converted to Power Output EF using an average fuel consumption of 7,000 BTU/hp-hr, which is equivalent to 9896 kJ/kWh.
3. In the source data the organic compounds are provided as Total Organic Compounds (TOC). To convert TOC to VOCs the following relationship was used to determine the VOCs: VOCs = TOC/1.1167.
4. Relates to the certainty of using the EF to determine pollutant levels. An Emission Factor Rating (EFR) rating of A indicates excellent certainty and E poor certainty. The EFR does NOT have to be reported as part of NPI requirements. See Section 4.4 for more detail.
5. To determine the EF based on volume of fuel used. For petrol and diesel in this Table the values of 34.36 and 38.21 MJ/L respectively were used to obtain this value (Reference 7, page 51).
6. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 14 Emission Factors (kg/m³) for Components of VOCs and PAHs from Uncontrolled Diesel Engines (Less Than 450kW)**

| Pollutant | Emission Factor Based on Fuel Input $(kg/m^3)$ |
|---|---|
| Acetaldehyde | 1.26E-02 |
| Benzene | 1.53E-02 |
| 1,3-Butadiene | < 6.43E-04 |
| Formaldehyde | 1.94E-02 |
| Total PAHs[4] | 2.76E-03 |
| Toluene | 6.72E-03 |
| Xylenes | 4.69E-03 |

Notes:
1. Source: Reference 5, Table 3.3-2.
2. To determine the EF based on volume of fuel used. For diesel in this table the value of 38.21 MJ/L was used (Reference 7, page 51).
3. PAHs = polycyclic aromatic hydrocarbons.
4. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 15 Emission Factors (kg/kWh & kg/m³) for Large (Greater Than 450kW) Diesel and Dual-Fuel Engines**

| Pollutant | Fuel – Diesel | | | Fuel - Dual-Fuel[2] | | |
|---|---|---|---|---|---|---|
| | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input ($kg/m^3$) | Emission Factor Rating[3] | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input ($kg/m^3$) | Emission Factor Rating[3] |
| CO | 3.34E-03 | 1.40E+01 | C | 4.56E-03 | 2.03E-02 | D |
| $NO_x$ | | | | | | |
| Uncontrolled[8] | 1.46E-02 | 5.26E+01 | B | 1.09E-02 | 4.72E-02 | D |
| Controlled | 7.90E-03 | 3.12E+01 | B | ND | ND | NA |
| $PM_{10}$ | 4.26E-04 | 1.64E+00 | B | ND | ND | NA |
| $SO_2$[5] | 4.92E-03$S_1$ | 1.66E+01$S_1$ | B | 2.47E-04$S_1$ + 5.82E-03$S_2$ | 8.74E-04$S_1$ + 1.56E-02$S_2$ | B |
| VOCs[9] | 3.84E-04 | 1.32E+00 | C | 8.03E-04 | 3.49E-03 | D |

Notes:
1. Source: Reference 6, Table 3.4-1.
2. Dual-fuel refers to 5 wt% diesel and 95 wt% natural gas.
3. An EFR of A indicates excellent certainty and E poor certainty. The EFR does NOT have to be reported as part of NPI requirements. See 4.4 for more detail.
4. ND - No data; NA - Not applicable.
5. $S_1$ and $S_2$ signify the fuel sulfur content (wt%) in the diesel and natural gas respectively. They are multiplied by the coefficient given to obtain the $SO_2$ EF. For example if sulfur content is 1.5%, then S = 1.5.
6. Energy content of natural gas and diesel is 38.9 MJ/$sm^3$ and 38.2 MJ/L respectively.
7. Natural gas is measured in Standard $m^3$ ($sm^3$).
8. Unless otherwise stated the engines are controlled.
9. The Non-methane TOC component from the original reference.
10. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 16 Emission Factors (kg/m³) of some VOCs components for Large (Greater than 450kW) Diesel Engines**

| Pollutant | Emission Factor Based on Fuel Input ($kg/m^3$) | Emission Factor Rating[2] |
|---|---|---|
| Acetaldehyde | 4.14E-04 | E |
| Benzene | 1.28E-02 | E |
| Formaldehyde | 1.30E-03 | E |
| Toluene | 4.62E-03 | E |
| Xylenes | 3.22E-03 | E |

Notes:
1. Source: Reference 6, Table 3.4-3.
2. Certainty of EF where an EFR of A indicates excellent certainty and E poor certainty. The EFR does NOT have to be reported as part of NPI requirements. See 4.4 for more detail.
3. Energy content of diesel fuel is 38.2 MJ/L.
4. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

Table 17 to Table 24 provides emission factors for natural gas combustion engines used mainly in the natural gas supply industry or where natural gas is the most plentiful supply of fuel. An example of this would be compressors in natural gas pipelines or hospital electricity generators. The engines specified are specific in terms of the number of being 2 or 4 stroke, whether they are lean or rich-burn and the type of emission control equipment utilised. To determine the specifications of the engine you are determining the emissions for refer to the engine manufacturer's specifications.

**Table 17 Emission Factors (kg/kWh & kg/m$^3$) for Uncontrolled Gas Turbine Natural Gas Engines**

| Pollutant | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input (kg/m$^3$) |
|---|---|---|
| Benzene | 2.20E-06 | ND |
| CO | 1.11E-03 | 2.85E-03 |
| Ethylbenzene | 1.10E-06 | ND |
| $NO_x$ | 1.74E-03 | 5.69E-03 |
| Toluene | 2.20E-06 | ND |
| VOCs[3] | 1.34E-05 | 3.35E-05 |
| Xylenes | 3.30E-06 | ND |

Notes:
1. Source: Reference 4, Table 3.2-1.
2. VOCs is the Total Non-Methane Organic Components.
3. Energy content of natural gas is 38.9 MJ/sm$^3$.
4. m$^3$ of natural gas refers to sm$^3$ @ 1 atm pressure and 15°C.
5. ND - No data.
6. Scientific notation is used; e.g. 7.38E-02 represents 7.38 x $10^{-2}$ or 0.0738.

Emission factors in Table 18 to Table 20 are more recent values incorporating a much wider range of NPI substances. When determining emissions for controlled engines select the table with the emission factors for the appropriate engine type and control strategy and determine the pollutant emissions for the pollutants. For additional pollutants use the uncontrolled emission factors for the appropriate engine. For example for a 2-stroke lean burn engine with increased air/fuel ratio with inter-cooling use Table 21 for the emission factors for CO, $PM_{10}$, $NO_x$, and VOCs and the other pollutant emissions are estimated from the emission factors in Table 18. If you believe you have more appropriate emission estimation techniques or emission factors contact your State or Territory jurisdiction to attain their advice as to whether they can be used for NPI reporting.

**Table 18 Emission Factors (kg/m3) for Uncontrolled 2-Stroke Lean-Burn Natural Gas Engines**

| Pollutant | Emission Factor Based on Fuel Input (kg/m$^3$) | Emission Factor Rating[2] |
|---|---|---|
| Acetaldehyde | 1.30E-04 | A |
| Benzene | 3.25E-05 | A |
| 1,3-Butadiene | 1.37E-05 | D |
| Chloroform | 7.88E-07 | C |
| CO (<90% Load) | 5.91E-03 | A |
| CO (90-105% Load) | 6.46E-03 | A |
| 1,2-Dichloroethane | 7.06E-07 | D |
| Ethylbenzene | 1.81E-06 | B |
| Formaldehyde | 9.24E-04 | A |
| n-Hexane | 7.45E-06 | C |

| Pollutant | Emission Factor Based on Fuel Input (kg/$m^3$) | Emission Factor Rating |
|---|---|---|
| Methanol | 4.15E-05 | A |
| $NO_x$ (<90% Load) | 3.25E-02 | A |
| $NO_x$ (90-105% Load) | 5.31E-02 | A |
| PAHs | 2.24E-06 | D |
| Phenol | 7.05E-07 | C |
| $PM_{10}$ | 6.43E-04 | C |
| $SO_2$ | 9.84E-06 | A |
| Styrene | 9.17E-07 | A |
| Toluene | 1.61E-05 | A |
| Vinyl Chloride | 4.13E-07 | C |
| VOCs | 2.01E-03 | C |
| Xylene | 4.49E-06 | A |

Notes:
1. Source: Reference 14, Table 3.2-1.
2. Relates to the certainty of using the EF to determine pollutant levels. An Emission Factor Rating (EFR) rating of A indicates excellent certainty and E poor certainty. The EFR does NOT have to be reported as part of NPI requirements. See Section 4.4 for more detail.
3. Energy content of natural gas is 38.9 MJ/$sm^3$.
4. $m^3$ of natural gas refers to $sm^3$ @ 1 atm pressure and 15°C.
5. Scientific notation is used; e.g. 7.38E-02 represents 7.38 x $10^{-2}$ or 0.0738.

**Table 19 Emission Factors (kg/m3) for Uncontrolled 4-Stroke Natural Gas Engines**

| Pollutant | Emission Factor Based on Fuel Input (kg/$m^3$) | Emission Factor Rating[2] |
|---|---|---|
| Acetaldehyde | 1.40E-04 | A |
| Benzene | 7.37E-06 | A |
| Biphenyl | 3.55E-06 | D |
| 1,3-Butadiene | 4.47E-06 | D |
| Chloroethane | 3.13E-08 | D |
| Chloroform | <4.77E-07 | E |
| CO (<90% Load) | 9.32E-03 | B |
| CO (90-105% Load) | 5.31E-03 | C |
| 1,2-Dichloroethane | <4.50E-07 | E |
| Ethylbenzene | 6.65E-07 | B |
| Formaldehyde | <8.84E-04 | A |
| n-Hexane | 1.86E-05 | C |
| Methanol | 4.19E-05 | B |
| $NO_x$ (<90% Load) | 1.42E-02 | B |
| $NO_x$ (90-105% Load) | 6.83E-02 | B |
| PAHs | 4.50E-07 | D |
| Phenol | 4.02E-07 | C |
| $PM_{10}$ | 1.29E-06 | D |
| $SO_2$ | 9.84E-06 | A |
| Styrene | 3.95E-07 | E |
| Toluene | 6.83E-06 | B |
| Vinyl Chloride | 2.49E-07 | C |

| Pollutant | Emission Factor Based on Fuel Input (kg/m$^3$) | Emission Factor Rating |
|---|---|---|
| VOCs | 1.98E-03 | C |
| Xylene | 3.08E-06 | B |

Notes:
1. Source: Reference 14, Table 3.2-2.
2. Relates to the certainty of using the EF to determine pollutant levels. An Emission Factor Rating (EFR) rating of A indicates excellent certainty and E poor certainty. The EFR does NOT have to be reported as part of NPI requirements. See Section 4.4 for more detail.
3. Energy content of natural gas is 38.9 MJ/sm$^3$.
4. m$^3$ of natural gas refers to sm$^3$ @ 1 atm pressure and 15°C.
5. Scientific notation is used; e.g. 7.38E-02 represents 7.38 x $10^{-2}$ or 0.0738.

**Table 20 Emission Factors (kg/m3) for Uncontrolled 4-Stroke Rich-Burn Natural Gas Engines**

| Pollutant | Emission Factor Based on Fuel Input (kg/m$^3$) | Emission Factor Rating[2] |
|---|---|---|
| Acetaldehyde | 4.67E-05 | C |
| Benzene | 2.64E-05 | B |
| 1,3-Butadiene | 1.11E-05 | D |
| Chloroform | <2.29E-07 | E |
| CO (<90% Load) | 5.88E-02 | C |
| CO (90-105% Load) | 6.23E-02 | A |
| 1,2-Dichloroethane | <1.89E-07 | E |
| Ethylbenzene | <4.15E-07 | E |
| Formaldehyde | 3.43E-04 | A |
| Methanol | 5.12E-05 | D |
| $NO_x$ (<90% Load) | 3.80E-02 | C |
| $NO_x$ (90-105% Load) | 3.70E-02 | A |
| PAHs | 2.36E-06 | D |
| $PM_{10}$ | 1.59E-04 | E |
| $SO_2$ | 9.84E-06 | A |
| Styrene | 1.99E-07 | E |
| Toluene | 9.34E-06 | A |
| Vinyl Chloride | 1.20E-07 | E |
| VOCs | 4.96E-04 | C |
| Xylene | 3.26E-06 | A |

Notes:
1. Source: Reference 14, Table 3.2-3.
2. Relates to the certainty of using the EF to determine pollutant levels. An Emission Factor Rating (EFR) rating of A indicates excellent certainty and E poor certainty. The EFR does NOT have to be reported as part of NPI requirements. See Section 4.4 for more detail.
3. Energy content of natural gas is 38.9 MJ/sm$^3$.
4. m$^3$ of natural gas refers to sm$^3$ @ 1 atm pressure and 15°C.
5. Scientific notation is used; e.g. 7.38E-02 represents 7.38 x $10^{-2}$ or 0.0738.

**Table 21 Emission Factors (kg/kWh & kg/m$^3$) for Controlled Natural Gas Engine Units: Combustion Modification on 2-Stroke Lean Burn Engine - Increased Air/Fuel Ratio with Inter-cooling**

| Pollutant | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input (kg/m$^3$) |
|---|---|---|
| CO | 2.01E-03 | 7.70E-03 |
| $NO_x$ | 6.69E-03 | 2.51E-02 |
| $PM_{10}$ | 2.41E-04 | 9.21E-04 |
| VOCs[3] | 7.90E-03 | 3.01E-02 |

Notes:
1. Source: Reference 4, Table 3.2-2
2. Certainty of EF is from the EFR. An EFR of A indicates excellent certainty and E poor certainty. The EFR for this data is E. The EFR does NOT have to be reported as part of NPI requirements. See 4.4 for more detail.
3. VOCs is the Total Non-Methane Organic Compounds (TNMOC).
4. Energy content of natural gas is 38.9 MJ/m$^3$.
5. Neg. = negligible levels present.
6. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 22 Emission Factors (kg/kWh & kg/m$^3$) for Controlled Natural Gas Engine Units: Clean Burn and Pre-combustion Chamber on 2–Stroke Lean Burn Engine**

| Pollutant | Clean Burn | | Pre-combustion Chamber | |
|---|---|---|---|---|
| | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input (kg/m$^3$) | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input (kg/m$^3$) |
| CO | 1.48E-03 | 5.02E-03 | 3.22E-03 | 1.12E-02 |
| $NO_x$ | 3.08E-03 | 1.39E-02 | 3.89E-03 | 1.42E-02 |
| VOCs[2] | 1.61E-04 | 2.51E-03 | 1.18E-03 | 4.19E-03 |

Notes:
1. Source: Reference 4, Table 3.2-5.
2. VOCs is the Total Non-Methane Organic Compounds (TNMOC).
3. Energy content of natural gas is 38.9 MJ/m$^3$.
4. neg. = negligible levels present.
5. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 23 Emission Factors (kg/kWh & kg/m$^3$) for Controlled Natural Gas Engine Units: Selective Catalytic Reduction on 4-Stroke Lean Burn Engine**

| Pollutant | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input (kg/m$^3$) |
|---|---|---|
| Ammonia | 5.95E-04 | 9.1E-02 |
| CO | 1.48E-03 | 6.19E-03 |
| $NO_x$ | 4.83E-03 | 2.01E-02 |
| VOCs[2] | 6.60E-06 | 3.15E-05 |

Notes:
1. Source: Reference 4, Table 3.2-4
2. VOCs are the $C_7$ to $C_{16}$ components.
3. Energy content of natural gas is 38.9 MJ/m$^3$.
4. neg. = negligible levels present.
5. The outlet emission factors (2 right hand columns) should be used when calculating the emissions released from this table in this manual.
6. If pollution abatement equipment is fitted and operating correctly the EFs from the pollution abatement equipment outlet should be used for estimating engine pollutant emissions.
7. ND - No data.
8. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

**Table 24 Emission Factors (kg/kWh & kg/m$^3$) for Controlled Natural Gas Engine Units: Non-Selective Catalytic Reduction on 4-Stroke Rich Burn Engine**

| Pollutant | Emission Factor Based on Power Output (kg/kWh) | Emission Factor Based on Fuel Input (kg/m$^3$) |
|---|---|---|
| Acetaldehyde | ND | <8.04E-08 |
| Ammonia | 1.10E-03 | 3.18E-03 |
| Benzene | ND | 1.84E-06 |
| 1,3-Butadiene | ND | ND |
| CO | 1.34E-02 | 4.02E-02 |
| Formaldehyde | ND | <1.21E-07 |
| $NO_x$ | 3.35E-03 | 9.71E-03 |
| PAHs[6] | ND | ND |
| $PM_{10}$ | 4.02E-06 | 1.17E-05 |
| VOCs[2] | 2.40E-04 | 7.05E-04 |
| Toluene | ND | 3.85E-07 |
| Xylenes | ND | <6.70E-07 |

Notes:
1. Source: Reference 4, Table 3.2-3.
2. VOCs = TOC/1.1167.
3. ND - No data.
4. Energy content of natural gas is 38.9 MJ/m$^3$.
5. neg. = negligible levels present.
6. PAHs = polycyclic aromatic hydrocarbons.
7. The outlet emission factors (2 right hand columns) should be used when calculating the emissions released from this table in this manual.
8. If pollution abatement equipment is fitted and operating correctly the EFs from the pollution abatement equipment outlet should be used for estimating engine pollutant emissions.
9. Scientific notation is used; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738.

### 3.4.10 Control Technologies

Table 25 summarises whether the various diesel emission reduction technologies, some of which may also be applicable to petrol engines, will generally increase or decrease the pollutant emissions. These technologies are categorised according to:

- fuel modifications

- engine modifications
- after-exhaust treatment

Current data is insufficient to quantify the results of these modifications, but Table 25 provides details of the resultant trends with regard to pollutants emission.

For large combustion engines (>450kW), control measures to date have been directed towards reducing $NO_x$ emissions, since $NO_x$ is the primary pollutant from diesel and dual-fuel engines. Table 26 shows the $NO_x$ reduction and fuel consumption penalties for diesel and dual-fuelled engines based on some of the available control techniques. All of these control techniques rely on engine modifications except Selective Catalytic Reduction (SCR), which is a post-combustion control technique. The pollutant emission decreases shown have been demonstrated, but the effectiveness of each technique can vary considerably.

Other $NO_x$ emission control techniques not listed in Table 26 are also used. These techniques include internal/external exhaust gas recirculation, combustion chamber modification, manifold air-cooling and turbo-charging.

The brake-specific fuel consumption (BSFC) of an engine is the engine's fuel consumption related to energy in the fuel rather than to the mass or volume of the fuel. This term is used as the energy content of fuels can vary significantly, even among fuels of the same type such as diesel. This is more the case in Europe and the US where there are much wider sources of fuel feedstock and fuel refineries. The value often used in the literature from which much of the data was derived (References 4 to 6) is 9 896 kJ/kWh (7 000 BTU/hp-h).

If a fuel has a significantly different energy content from that used to determine the emission factor on a volume-of-fuel-used basis, the emission factor should be changed. The fuel energy content assumed when determining the emission factor on a volume-of-fuel-used basis is stated in all cases for stationary combustion engines, Table 13 to Table 24. To convert to emission factors based on the quantity of fuel to a value relevant to the same type of fuel, but with different energy content, knowledge of the fuel's energy content is required as shown in Equation 12. The energy content values used in Equation 12 ($H_1$ and $H_2$) need to have the same units.

$$EF_1 = EF_2 * \left( H_1 / H_2 \right)$$ Equation 12

where:

| | | |
|---|---|---|
| $EF_1$ | = | new EF for fuel with different heat content |
| $EF_2$ | = | old EF for fuel with initial heat content |
| $H_1$ | = | fuel heat content of new fuel - see fuel specifications from supplier, MJ/L |
| $H_2$ | = | fuel heat content of original fuel - see table where $EF_2$ is obtained, MJ/L or $MJ/m^3$ for natural gas |

**Table 25 Diesel Engine Emission Control Technologies**

| Technology | Affected Parameter | |
|---|---|---|
| | Increase | Decrease |
| ***Fuel Modifications*** | | |
| Sulfur content increase | $PM_{10}$, wear | |
| Aromatic content increase | $PM_{10}$,$NO_x$ | |
| Cetane number | | $PM_{10}$,$NO_x$ |
| 10% and 90% boiling point | | $PM_{10}$ |
| Fuel additives | | $PM_{10}$,$NO_x$ |
| Water/Fuel emulsions | | $NO_x$ |
| ***Engine Modifications*** | | |
| Injection timing retard | $PM_{10}$, BSFC | power, $NO_x$ |
| Fuel injection pressure | $PM_{10}$,$NO_x$ | |
| Injection rate control | | $PM_{10}$,$NO_x$ |
| Rapid spill nozzles | | $PM_{10}$ |
| Electronic timing and metering | | $PM_{10}$,$NO_x$ |
| Injection nozzle geometry | | $PM_{10}$ |
| Combustion chamber modifications | | $PM_{10}$,$NO_x$ |
| Turbocharging | $PM_{10}$, power | $NO_x$ |
| Charge cooling | | $NO_x$ |
| Exhaust gas recirculation | $PM_{10}$, power | $NO_x$ |
| Oil consumption control | | $PM_{10}$, wear |
| ***Exhaust After-Treatment*** | | |
| Particulate traps | | $PM_{10}$ |
| Selective catalytic reduction | | $NO_x$ |
| Oxidation catalysts | | $PM_{10}$, CO, VOCs |
| Notes: 1. Source: Reference 5, Table 3.3-3. | | |

Table 26 shows the impact of various $NO_x$ reduction techniques on the fuel consumption of diesel and diesel/natural gas engines. It is common for pollutant emission reduction equipment to decrease engine performance and this has to be considered before deciding to implement any emission reduction strategies.

**Table 26 $NO_x$ Reduction and Fuel Consumption Penalties for Large Stationary Diesel and Dual-Fuel Engines**

| Control Approach | Diesel | | Dual-Fuel | |
|---|---|---|---|---|
| | $NO_x$ Reduction (%) | Δ BSFC[3] (%) | $NO_x$ Reduction (%) | Δ BSFC[3] (%) |
| ***Derate*** 10% | ND | ND | <20 | 4 |
| 20% | <20 | 4 | ND | ND |
| 30% | 5 - 23 | 1 - 5 | 1 - 33 | 1 - 7 |
| ***Retard*** | | | | |
| 2 ° | <20 | 4 | <20 | 3 |
| 4 ° | <40 | 4 | <40 | 1 |
| 8 ° | 28 - 45 | 2 - 8 | 50 - 73 | 3 - 5 |
| ***Air to Fuel*** 3% | ND | ND | <20 | 0 |
| ± 10% | 7 - 8 | 3 | 25 - 40 | 1 - 3 |
| ***Water Injection (H₂O/fuel ratio)*** 50% | 25 - 35 | 2 – 4 | ND | ND |
| ***Selective Catalytic Reduction*** | 80 - 95 | 0 | 80 - 95 | 0 |

Notes
1. Source: Reference 6, Table 3.4-5.
2. The reductions shown are typical and will vary depending on the engine and duty cycle.
3. ΔBSFC = change in brake-specific fuel consumption.
4. ND = no data.

# 4 Emission Estimation Techniques: Acceptable Reliability and Uncertainty

This section is intended to give an overview of some of the errors associated with the EETs outlined in this Manual. The NPI encourages the use of the most accurate EET possible. This section briefly evaluates the accuracy of available EETs.

Several techniques are available for calculating pollutant emission from combustion engines. The technique chosen will depend on available data and resources. The EET used will affect the degree of accuracy attained for the pollutant emission estimate. In general, site-specific data representative of normal operations is more accurate than industry-averaged data (such as the emission factors in 3.4 in this Manual).

### 4.1 Direct Measurement

The use of stack and/or workplace health and safety sampling data is likely to be a more accurate method of estimating pollutant emissions from combustion engines than other EETs in this manual. Collection and analysis of samples from sample points can be very expensive and complicated where a variety of NPI-listed substances are emitted and most of these emissions are fugitive in nature. Additionally, sampling data from one specific process may not be representative of the entire manufacturing operation and may provide only one example of the operation's pollutant emissions.

For data to be representative the sampling used for NPI reporting needs to be collected over a significant period and to cover all pollutant emission situations.

In the case of CEMS, instrument calibration drift can be a problem and uncaptured data can create incomplete data sets that make estimates of pollutant emission prone to large errors. However, it may be misleading to assert that a snapshot, such as stack sampling, can better predict long-term pollutant emission than CEMS. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and to ensure the pollutant emission data is representative of pollutant emissions from the facility.

### 4.2 Mass Balance

Calculating pollutant emissions from combustion engines using a mass balance is not straightforward. Many facilities have a detailed knowledge of the fuel types and quantities used but do not have a good measure of the emissions released from their combustion engines. Because chemical reactions that take place within combustion engines change the nature of the fuel used, the quantity and concentration of products released from combustion engines must be measured. For example, pollutant emissions from combustion engines are typically less than 2 wt% of fuel consumption; an error of only ± 5 wt% in determining the concentration or flow of any of the outputs can make pollutant emission estimates of low accuracy.

### 4.3 Engineering Calculations

Theoretical and complex equations or models based on the chemical and physical steps of combustion within the combustion engine can be used to estimate pollutant emission levels. However, the theoretical equations and models are often not developed to the stage where pollutant emission levels of acceptable accuracy can be estimated. Additionally, theoretical and complex equations or models require more detailed inputs than the use of emission factors, but may provide an emission estimate based on facility-specific conditions. Use of theoretical equations and models to estimate emissions from combustion engines is more complex and time-consuming than the use of emission factors based on simple engine characteristics such as power or fuel consumption and may not provide a better estimate of pollutant emissions.

## 4.4 Emission Factor Rating and Accuracy.

Most emission factors have an associated Emission Factor Rating (EFR) code. This EFR rating system is common to EETs for all industries and sectors and hence all Industry Handbooks, and is based on rating systems developed by the United States Environmental Protection Agency (USEPA) and the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited in this Manual can be found in the reference section. The EFR 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. A rating of A indicates the greatest degree of certainty and E the lowest. The less certainty, the more likely that a given emission factor for a specific source or category may not be 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 or process selected in applying the factor and the equipment or process from which the emission factor was derived.

The EFR system is as follows:

A - Excellent

B - Above Average

C - Average

D - Below Average

E - Poor

U - Unrated

In addition to the EFR code, the accuracy of emission factors is thoroughly dependent on the degree of similarity between the reference source and the emission source being estimated.

# 5 Glossary of Technical Terms and Abbreviations

**Table 27 Glossary of Technical Terms and Abbreviations used in this Manual**

| Term | Definition |
|---|---|
| Adiabatic flame temperature | Flame temperature from combustion of fuels under adiabatic conditions (when there is no energy into or out of the combustion system), i.e. the heat released from combustion goes to heat the combustion products only. Also referred to as adiabatic temperature |
| BSFC | Brake-specific fuel consumption |
| BHP | Brake horsepower – power from the engine excluding losses caused by the gearbox, differential, water pump and other auxiliaries. This is the value used in this manual when engine power is referred to.<br>(note: In this manual the emission factors are often in terms of kg/kW. To convert to kW use the factor 1hp = 0.7456kW) |
| CEMS | Continuous emission monitoring systems |
| CNG | Compressed natural gas |
| CO | Carbon monoxide - a gaseous pollutant released from combustion |
| Den | Fuel density, kg/m$^3$ |
| EEA | European Environment Agency |
| EET | Emission estimation technique |
| EF | Emission factor |
| $EF_i$ | Emission factor for pollutant i in terms of engine power, kg/kWh |
| $EF_1$ | New EF for fuel with different heat content |
| $EF_2$ | Old EF for fuel with initial heat content |
| EFR | Emission Factor Rating |
| EFs | Emission factors |
| $E_{kpy,i}$ | Emission of pollutant i per year, kg/yr |
| F | Fuel volume used in NPI reporting year, m$^3$ |
| FW | Fuel weight used in NPI reporting year, kg |
| $H_1$ | Fuel heat content of new fuel - see fuel specifications from supplier, MJ/L |
| $H_2$ | Fuel heat content of original fuel - see table from which EF is obtained, MJ/L |
| HGV | Heavy Goods Vehicle |
| hp | Horsepower: unit of measuring engine power. Check conversion tables in Appendix 1 for further conversion factors |
| i | Pollutant component whose emission level is being determined |
| hr | Hour |
| kW | Kilowatt: unit of measuring engine power. This is the unit for engine power mostly used in this manual. Check conversion tables in Appendix 1 for further conversion factors |
| L | Litre |
| LF | Engine load factor: the average engine power output divided by the rated engine power |
| LGV | Light Goods Vehicle |
| LPG | Liquid petroleum gas - usually propane and/or butane |
| NA | Not applicable |

**Table 24 Glossary of Technical Terms and Abbreviations used in this Manual (cont.)**

| Term | Definition |
|---|---|
| ND | No data |
| $sm^3$ | Standard cubic metres of gas, i.e. at 15°C and 1 atm pressure |
| $NO_x$ | Nitrogen oxides released during combustion processes |
| NPI | National Pollutant Inventory |
| OEM | Original equipment manufacturer |
| OpHrs | Annual operating hours for the engine whose emissions are being estimated, h/yr |
| PAHs | Polycyclic aromatic hydrocarbons: group of light aromatic gaseous pollutants released from combustion. |
| $PM_{10}$ | Particulate matter equal to or less than 10µm in aerodynamic diameter |
| Prime mover | The stationary engine which is the main supplier of force or power for a given situation |
| QDE & A | Queensland Department of Environment and Heritage |
| Scientific notation | Scientific notation is used for much of the data in this manual; e.g. 7.38E-02 represents $7.38 \times 10^{-2}$ or 0.0738 |
| SCR | Selective catalytic reduction |
| $SO_2$ | Sulfur dioxide: a gaseous pollutant released from combustion |
| TNMOC | Total Non-Methane Organic Compounds |
| TOC | Total organic compounds |
| USEPA | United States Environmental Protection Agency |
| VOCs | Total volatile organic compounds |
| yr | Year |

# 6 References


1. Eastern Research Group. July 1997. *Introduction to Stationary Point Source Emission Inventory Development Volume II: Chapter 1.* Morrisville, NC, USA.
2. Energy and Environmental Analysis Inc. December 1988. *Feasibility of Controlling Emissions From Off-Road, Heavy-Duty Construction Equipment.* Prepared for the Air Resources Board, Sacramento, Arlington, VA, USA.
3. Energy and Environmental Analysis Inc. January 1992. *Regulatory Strategies for Off-Highway Equipment.* Prepared for the Air Resources Board, Sacramento, Arlington, VA, USA.
4. USEPA. October 1996. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fifth edition, AP-42. Section 3.2 Heavy-Duty Natural Gas-Fired Pipeline Compressor Engines and Turbines.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.
   *(available at http://www.epa.gov/ttn/chief/ap42etc.html#LE as at February 2000 ).*
5. USEPA. October 1996. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fifth edition, AP-42. Section 3.3 Stationary Internal Combustion Sources - Gasoline and Diesel Industrial Engines.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.
   *(available at http://www.epa.gov/ttn/chief/ap42etc.html#LE as at February 2000 ).*
6. USEPA. October 1996. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fifth edition, AP-42. Section 3.4 Stationary Internal Combustion Sources - Large Stationary Diesel and Dual Fuel Industrial Engines.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.
   *(available at http://www.epa.gov/ttn/chief/ap42etc.html#LE as at February 2000 ).*
7. AIE. 1988. *Queensland Energy Directory 1988.* The Australian Institute of Energy.
8. Perry, R.H., Green, D.W. and Maloney, J.O. (eds). 1984. *Perry's Chemical Engineers' Handbook,* 6th ed., McGraw Hill Book Company, New York, USA.
9. Weast, R.C. (ed.). 1983. *CRC Handbook of Chemistry and Physics*, 64th ed., CRC Press Inc., Boca Raton, Florida.
10. USEPA September 1985. *Compilation of Air Pollutant Emission Factors, Volume 2: Mobile Sources, fourth edition, A-42. Section 2.7 Heavy Duty Construction Equipment.* United States Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources Test and Evaluation Branch Ann Arbor, Michigan, USA.
11. The UK Emission Factors Database.
    *(available at http://www.london-research.gov.uk/emission/roads.htm as at May 2000 ).*
12. Boyle, R., Dewundege, P., Házi, Hearn, D., McIntosh, C., Morrell, A., Ng, Y.L., and Serebryanikova, R., EPA - State Government of Victoria September 1996. Technical Report on the air emissions trials *for the* National Pollutant Inventory, Volume 2, Australia.
13. Anyon, P., Parsons Australia Pty. Ltd. August 1998. Liquefied Petroleum Gas as an Automotive Fuel *An Environmental and Technical Perspective*, for Australian Liquefied Petroleum Gas Association Ltd., Australia.
14. USEPA. July 2000. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fifth edition, AP-42. Section 3.2 Natural Gas-Fired Pipeline Reciprocating Engines.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.
15. Vic EPA, Passenger road vehicle emission work completed between 1990 and 1998.

# Appendix 1 Useful Unit Conversion Factors and Fuel Physical Properties Relating to Combustion Engines

As in most fields of engineering, when examining combustion engines and their emissions, there is a range of measurement units with which physical quantities are measured.

To assist in converting units a summary of various engineering unit conversion constants is provided. There are many more comprehensive sources of conversion data, for example Reference 8.

The conversion constants below are grouped as follows:

- Power
- Weight
- Volume
- Length
- Other Units

**Table 28 Useful Conversion Factors in Relation to Determining Emissions from Combustion Engines**

| To Convert From | To | Multiply By |
|---|---|---|
| ***Power*** | | |
| hp – horsepower | kW - kilowatts | 7.456E-01 |
| ***Weight*** | | |
| kg – kilograms | lb - pounds | 2.205E+00 |
| ***Volume*** | | |
| UK gallon | $m^3$ - cubic metres | 4.546E-03 |
| US gallon | $m^3$ - cubic metres | 3.785E-03 |
| L – litres | $m^3$ - cubic metres | 1.00E-03 |
| ***Length*** | | |
| m – metres | km - kilometres | 1.000E-03 |
| mile | km - kilometres | 1.609E+00 |
| ***Other Units*** | | |
| MMBTU | BTU | 1.000E+06 |
| lb/hp-h | kg/kWh | 6.080E-01 |
| BTU | J | 1.054E+03 |

**Table 29 Fuel Physical Properties Useful in Determining Emissions from Combustion Engines**

| Fuel | Description and Properties |
|---|---|
| Diesel | Also called automotive distillate. Density = 8.361E+02 kg/$m^3$<br>Heating value = 38.21 MJ/L (Source: Reference 7, page 51) |
| Petrol | Also called motor spirit. Density = 7.391E+02 kg/$m^3$<br>Heating value = 34.36 MJ/L (Source: Reference 7, page 51) |
| Natural Gas | Also called natural gas (Queensland). Density = 6.963E-01 kg/$sm^3$<br>Heating value = 38.9 MJ/$sm^3$ (Source: Reference 7, page 51) |

# Appendix 2 Worksheet to Determine Emissions from Vehicles

| | | | |
|---|---|---|---|
| ***Step 1*** | Determine if vehicle is used under road-transport or industrial conditions.<br>Circle driving conditions here.<br>(depending under which conditions the vehicle is most used) | Road-Transport / Industrial | **A** |
| ***Step 2*** | Determine vehicle engine power (P) in kW or fuel use (F) in litres (kg for LPG) and load factor (LF) if used under industrial conditions. | | |
| | Engine power (kW) of fuel use (litres or kg for LPG) | | **B** |
| | Load Factor<br>(for cars and utilities the LF is 0.25) | | **C** |
| ***Step 3*** | Determine vehicle operating hours for the reporting year.<br>(industrial vehicles and road-transport vehicles used under industrial vehicle conditions only) | | **D** |
| ***Step 4*** | Determine road-transport distance travelled ($L_Y$). | | |
| | Distance travelled (km) | | **F** |
| ***Step 5*** | Select the appropriate EF values for vehicles and calculate emissions. Use Table 3 to Table 11 as required. Include crankcase and evaporative EFs from Table 11 if required. | | **G** |

For industrial vehicles (based on engine power)

| Pollutants | Power<br>**B** | Industrial OpHrs<br>**D** | LF<br>**C** | Industrial $EF_i$<br>**G** | Emissions (kg/yr) $E_{kpy,i}$<br>**H = B*D*C*G** |
|---|---|---|---|---|---|
| CO | | | | | |
| Formaldehyde | | | | | |
| $NO_x$ | | | | | |
| $PM_{10}$ | | | | | |
| $SO_2$ | | | | | |
| VOCs | | | | | |

For industrial vehicles (based on fuel use)

| Pollutants | Fuel Use<br>**B** | LF<br>**C** | Industrial $EF_i$<br>**G** | Emissions (kg/yr) $E_{kpy,i}$<br>**H = B*C*G** |
|---|---|---|---|---|
| CO | | | | |
| Formaldehyde | | | | |
| $NO_x$ | | | | |
| $PM_{10}$ | | | | |
| $SO_2$ | | | | |
| VOCs | | | | |

Continued next page.

For road-transport vehicles (based on distance travelled)

| | Distance (km)<br><br>**F** | Road-Transport (kg/km)<br>$EF_i$<br>**G** | Emission (kg/yr)<br>$E_{kpy,i}$<br>**H = F*G** |
|---|---|---|---|
| Benzene | | | |
| 1,3 Butadiene | | | |
| CO | | | |
| $NO_x$ | | | |
| $PM_{10}$ | | | |
| $SO_2$ | | | |
| VOCs | | | |

# Appendix 3 Worksheet to Estimate Vehicle Operating Hours

Use 3.4.4 to estimate the vehicle operating hours (OpHrs) for the year.

This can be used in step 2 of calculating industrial or road-transport vehicle emissions. See Appendix 2 for worksheet to calculate vehicle emissions.

$$OpHrs = OpHrs_P * L_Y / L_P$$ Equation 7

***Step 1*** Choose period of typical operation of at least 4 weeks to obtain typical operating data for the vehicle.

***Step 2*** Log and determine the operating hours ($OpHrs_{p)}$ for the period of typical operation. **A**

***Step 3*** Determine the distance travelled by the vehicle for the entire NPI reporting year. Taking the odometer reading at the start and finish of the NPI reporting year will achieve this. **B**

***Step 4*** Determine the distance travelled for the period of typical operation. Taking the odometer reading at the start and finish of the period of typical operation will achieve this. **C**

***Step 5*** Calculate the NPI reporting year operating hours (OpHrs) using Equation 7.

$$OpHrs = OpHrs_P * L_Y / L_P$$ Equation 7

$$OpHrs = A * B / C = D$$ **D**

This can be used in step 2 of calculating industrial vehicle emissions. See Appendix 2 for worksheet to calculate vehicle emissions.

# Appendix 4 Classification of typical vehicles used by Australian Industry

**Table 30 Classification of various road-transport and industrial vehicles**

| **Road-Transport Vehicles** | |
|---|---|
| **Classification** | **Description** |
| Cars | – Small 4 wheel drive (4WD) vehicles such as Suzuki and Daihatsu<br>– 2 wheel drive (2WD) utilities less than tonne<br>– Other 2WD passenger cars |
| LGV – Light Goods Vehicle | – Large 4WD vehicles such as Toyota Landcruisers and Nissan Patrols<br>– Non-articulated trucks less than 4 tonnes nett<br>– Mini-buses for between 8 and 20 passengers |
| HGV – Heavy Goods Vehicles | – Non-articulated trucks of 4 tonnes net or more |
| Buses | – Buses carrying 20 passengers or more |
| **Industrial Vehicles** | |
| **Classification** | **Description or examples** |
| Track type tractor | – Bulldozer with blade for pushing and scraping |
| Wheeled tractor | – Tractor for towing equipment |
| Wheeled dozer | – Tractor with blade for pushing and scraping |
| Scraper | – Wheel tractor-scrapers |
| Motor grader | – Road grader |
| Wheeled loader | – Wheel loaders with bucket to load trucks etc. |
| Track type loader | – Track loaders with bucket to load trucks etc. |
| Off-highway truck | – Haul trucks used at mines |
| Roller | – Steam roller |
| Miscellaneous | – Forklift<br>– Aircraft tug<br>– Equipment tug |