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for

Combustion engines
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EMISSION ESTIMATION TECHNIQUES
FOR
COMBUSTION ENGINES
TABLE OF CONTENTS

1 INTRODUCTION 1
1.1 The process for NPI reporting 2
1.2 Information required to produce an annual NPI report 2
1.3 Additional reporting materials 3
2 PROCESSES 4
2.1 Process descriptions 4
2.1.1 Petrol and diesel industrial engines 5
2.1.2 Large stationary diesel and all stationary dual-fuel engines 5
2.1.3 Heavy-duty natural gas fired pipeline compressor engines and turbines 5
3 EMISSION SOURCES 7
3.1 Emissions to air 7
3.2 Emissions to water 8
3.3 Emissions to land 8
4 THRESHOLD CALCULATIONS 9
5 EMISSION ESTIMATION TECHNIQUES 12
5.1 Direct measurement 13
5.1.1 Sampling data 13
5.1.2 Continuous Emission Monitoring System (CEMS) data 14
5.2 Mass balance 14
5.3 Engineering calculations 14
5.3.1 Fuel analysis method for estimation of SO_2 14
5.3.2 Fuel analysis method for estimation of fluoride 15
5.4 Emission factors 16
5.4.1 Emission estimates for combustion engine powered vehicles 21
5.4.1.1 Road-transport vehicles 23
5.4.1.2 Industrial vehicles 23
5.4.2 Emission estimates from stationary combustion engines 29
5.4.2.1 Engine power method to estimate emissions from stationary combustion engines 30
5.4.2.2 Estimating stationary engine fuel consumption 35
5.4.3 Control technologies 36
5.5 Approved alternative 39
6 TRANSFERS OF NPI SUBSTANCES IN WASTE 40
7 EMISSION ESTIMATION TECHNIQUES: ACCEPTABLE RELIABILITY AND UNCERTAINTY 41
7.1 Direct measurement 41
7.2 Mass balance 41
7.3 Engineering calculations 42
7.4 Emission factor rating and accuracy 42
8 NEXT STEPS FOR REPORTING 44

9 REFERENCES 45

Appendix A : Definitions and abbreviations 47
Appendix B : Emission factors 49
B.1 Road transport vehicles 49
B.2 Industrial vehicles 59
B.3 Stationary engines 69
Appendix C : Useful unit conversion factors and fuel physical properties relating to combustion engines 82
Appendix D : Classification of typical vehicles used by Australian industry 83
Appendix E : Modifications to the Combustion engines emission estimation technique (EET) manual (October 2003) 83

EMISSION ESTIMATION TECHNIQUES
FOR
COMBUSTION ENGINES
LIST OF TABLES

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 13
Table 2: Emission factor summary for road transport vehicles 18
Table 3: Emission factor summary for industrial vehicles.. 19
Table 4: Emission factor summary for stationary engines.. 20
Table 5: Load factors for various “miscellaneous” industrial vehicles................................... 27
Table 6: Diesel engine emission control technologies 38
Table 7: NO_x reduction and fuel consumption penalties for large stationary diesel and dual-fuel engines 39
Table 8: Glossary of technical terms and abbreviations used in this manual 47
Table 9: Emission factors (kg/m³) for diesel vehicle exhaust emissions (car)......................... 49
Table 10: Emission factors (kg/km) for road transport vehicles - petrol cars 50
Table 11: Emission factors (kg/m³) for road transport vehicles - petrol cars........................... 50
Table 12: Emission factors (kg/km) for road transport vehicles – LPG cars 51
Table 13: Emission factors (kg/m³) for road transport vehicles – LPG cars............................ 51
Table 14: Emission factors (kg/m³) for passenger cars operating on E10 blends 52
Table 15: Emission factors (kg/m³) for diesel vehicle exhaust emissions (LGV) 52
Table 16: Emission factors (kg/km) for road transport vehicles - petrol LGVs 53
Table 17: Emission factors (kg/m³) for road transport vehicles - petrol LGVs 53
Table 18: Emission factors (kg/km) for road transport vehicles – LPG LGVs........................ 54
Table 19: Emission factors (kg/m³) for road transport vehicles – LPG LGVs 54
Table 20: Emission factors (kg/m³) for diesel vehicle exhaust emissions (MGV) 55
Table 21: Emission factors (kg/m³) for diesel vehicle exhaust emissions (HGV)................... 55
Table 22: Emission factors (kg/m³) for diesel vehicle exhaust emissions (very HGV)........... 56
Table 23: Emission factors (kg/m³) for diesel commercial vehicle exhaust emissions (bus) .. 56
Table 24: Emission factors (kg/m³) for natural gas buses and trucks 57
Table 25: Emission factors (kg/m³) for LPG forklift emissions 58
Table 26: Emission factors (kg/kWh) for diesel industrial vehicle (track-type tractor) exhaust emissions 59
Table 27: Emission factors (kg/kWh) for diesel industrial vehicle (wheeled tractor) exhaust emissions 59
Table 28: Emission factors (kg/kWh) for diesel industrial vehicle (wheeled dozer) exhaust emissions 60
Table 29: Emission factors (kg/kWh) for diesel industrial vehicle (scraper) exhaust emissions 60
Table 30: Emission factors (kg/kWh) for diesel industrial vehicle (motor grader) exhaust emissions 61
Table 31: Emission factors (kg/kWh) for diesel industrial vehicle (wheeled loader) exhaust emissions 61
Table 32: Emission factors (kg/kWh) for diesel industrial vehicle (track type loader) exhaust emissions 62
Table 33: Emission factors (kg/kWh) for diesel industrial vehicle (off-highway truck) exhaust emissions 62
Table 34: Emission factors (kg/kWh) for diesel industrial vehicle (roller) exhaust emissions 63
Table 35: Emission factors (kg/kWh) for diesel industrial vehicle (miscellaneous) exhaust emissions 63

Table 36: Emission factors (kg/kWh) for petrol industrial vehicle (wheeled tractor) exhaust emissions 64
Table 37: Emission factors (kg/kWh) for petrol industrial vehicle (motor grader) exhaust emissions 65
Table 38: Emission factors (kg/kWh) for petrol industrial vehicle (wheeled loader) exhaust emissions 66
Table 39: Emission factors (kg/kWh) for petrol industrial vehicle (roller) exhaust emissions 67
Table 40: Emission factors (kg/kWh) for petrol industrial vehicle (miscellaneous) exhaust emissions 68
Table 41: Emission factors (kg/kg LPG) for miscellaneous LPG industrial vehicle exhaust emissions 68
Table 42: Emission factors (kg/kWh) for stationary large (greater than 450 kW) diesel engines 69
Table 43: Emission factors (kg/m^3) for stationary large (greater than 450 kW) diesel engines 70
Table 44: Emission factors (kg/kWh) for stationary large (greater than 450 kW) dual fuel engines (fuel mixture of up to 25% waste oil and diesel)[5] 71
Table 45: Emission factors (kg/m^3) for stationary large (greater than 450 kW) dual fuel engines (fuel mixture of up to 25% waste oil with diesel fuel)[5] 72
Table 46: Emission factors (kg/kWh) for dual fuel engines (fuel mixture of up 95% natural gas and 5% diesel)[2] 73
Table 47: Emission factors (kg/m^3) for dual fuel engines (fuel mixture of up 95% natural gas and 5% diesel)[2] 73
Table 48: Emission factors (kg/m^3) for uncontrolled dual fuel (NG/diesel) engines (fuel mixture of 90% natural gas and 10% diesel) 74
Table 49: Emission factors (kg/kWh) for stationary small (less than 450 kW) diesel engines 75
Table 50: Emission factors (kg/m^3) for stationary small (less than 450 kW) diesel engines ... 76
Table 51: Emission factors (kg/kWh) for uncontrolled gas turbines natural gas engines 77
Table 52: Emission factors (kg/m^3) for uncontrolled gas turbines natural gas engines 77
Table 53: Emission factors (kg/m^3) for uncontrolled 2-stoke lean burn natural gas engines .. 78
Table 54: Emission factors (kg/m^3) for uncontrolled 4-stoke natural gas engines 79
Table 55: Emission factors (kg/Nm^3 fuel) for uncontrolled 4-stroke reciprocating stationary engines (biogas) 79
Table 56: Emission factors (kg/kWh) for uncontrolled 4-stroke reciprocating stationary engines (biogas) 80
Table 57: Emission factors (kg/m^3) for uncontrolled 4-stoke rich burn natural gas engines ... 80
Table 58: Emission factors (kg/m^3) for uncontrolled landfill gas fired turbines 81
Table 59: Emission factors (kg/kWh) for uncontrolled landfill gas fired turbines 81
Table 60: Useful conversion factors in relation to determining emissions from combustion engines 82
Table 61: Fuel physical properties useful in determining emissions from combustion engines 82

1 Introduction

The purpose of all emission estimation technique (EET) manuals is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This manual describes the procedures and recommended approaches for estimating emissions from combustion engines.

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

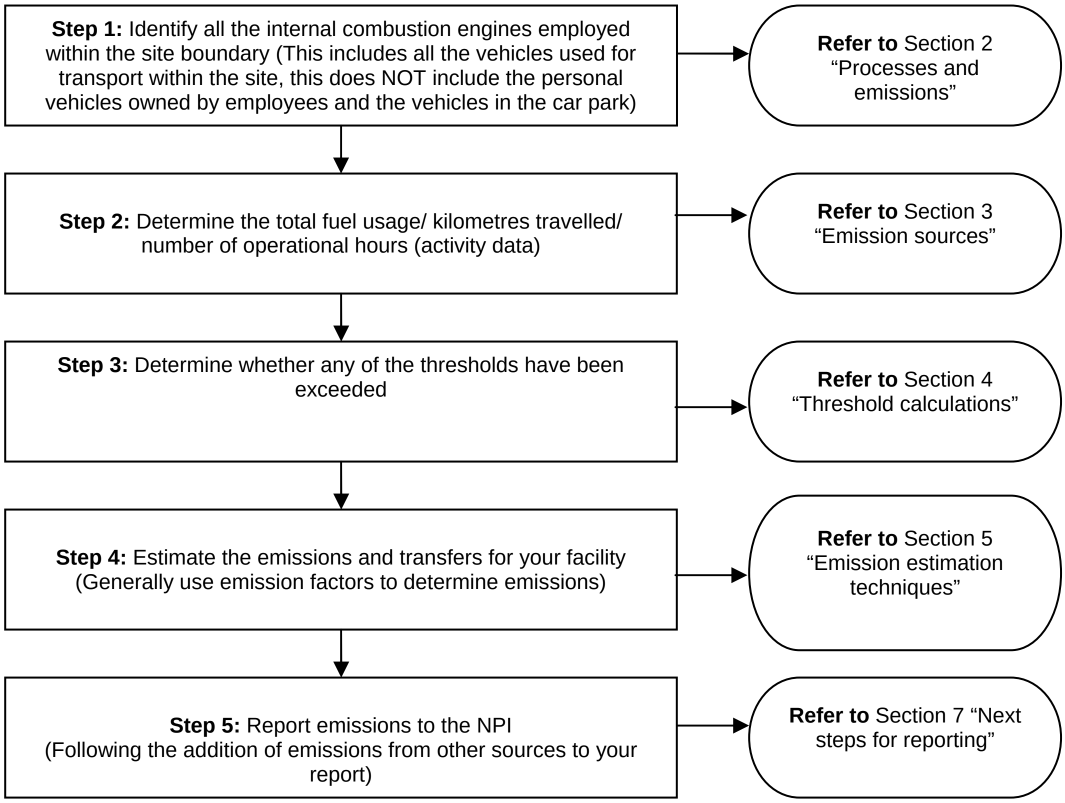
EET MANUAL	Combustion engines
ANZSIC 2006	Any industry sector where fuel is burned for internal combustion, i.e. ANZSIC 2006 Divisions A – S.

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

NPI substances are those that when emitted at certain levels have potential to be harmful. Australian, state and territory governments have agreed, in response to international requirements, that industries will report these emissions on an annual basis. NPI substances are set out in the *NPI Guide* and are listed in categories which have a threshold; i.e. once annual 'use' of substances is above the threshold their emissions and transfers must be reported.

1.1 The process for NPI reporting

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



1.2 Information required to produce an annual NPI report

The following data will need to be collated for the reporting period:

- all types of internal combustion engines including on-site vehicles (excluding the personal vehicles owned by employees);
- types of fuel used in all the combustion engines on-site;
- total fuel usage/ kilometres travelled/ number of operational hours for each type of combustion engine on-site; and
- pollution control devices employed.

1.3 Additional reporting materials

This manual is written to reflect the common process involved in estimating the emissions from internal combustion engines. In many cases it will be necessary to refer to other EET manuals to ensure a complete report of the emissions for the facility can be made. Other applicable EET manuals may include, but are not limited to:

- Combustion in boilers,
- Fuel and organic liquid storage,
- Fugitive emissions, and
- Other industry-specific emission estimation technique manuals.

2 Processes

The following section presents a brief description of combustion engines.

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 substance emissions it is the characteristics of the engine more than the equipment the engine drives that are important. Figure 1 illustrates the basic combustion engine process.

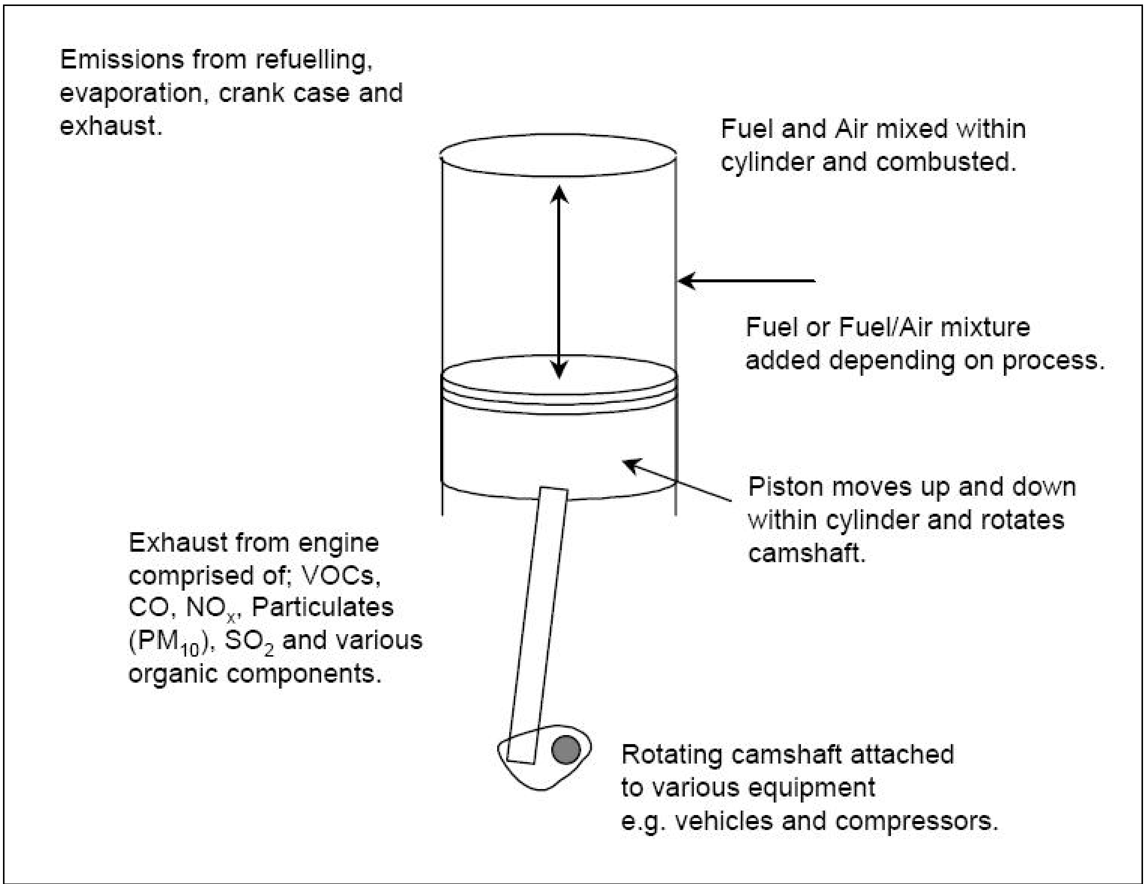


Figure 1: Basic combustion engine process (Source: Queensland Department of Environment and Heritage 1998)

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.

2.1.1 Petrol and diesel industrial engines

The three primary fuels for combustion engines are petrol, diesel (also called distillate 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 1,000 kW (1,340 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 5.4.1. Stationary engines are those that do not power vehicles but are used for some other operation and are covered in Section 5.4.2. 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 may 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 Section 5.4.2 and the use of two different emission estimation techniques (EETs) is outlined. The first method based on engine power and operating hours is covered in Section 5.4.2.1. The second method based on engine fuel consumption is covered in Section 5.4.2.2.

Emission factors used to estimate stationary combustion engine emissions for non-natural gas, liquid fuel engines and for heavy-duty natural gas engines and turbines are listed in Appendix B3.

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 engines are 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 5.4.2.1, or fuel consumption technique, Section 5.4.2.2, can be used to estimate emissions. The emission factors for this category of engines are listed in Appendix B3.

3 Emission sources

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 3.1, 3.2 and 3.3 respectively.

3.1 Emissions to air

Substance emissions to air may be categorised as fugitive or 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 exhaust emissions from vehicles, evaporative emissions from vehicle fuel tanks, volatilisation of vapour from vats or fuel tanks, open vessels, spills and materials handling. Emission factors are the EETs most commonly used for estimating fugitive emissions.

- **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 substances from combustion engines are emitted through the exhaust. Some volatile organic compounds (TVOCs) 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 due to evaporation). Nearly all the TVOCs from diesel combustion engines enter the atmosphere from the exhaust. Crankcase blow-by is minor because TVOCs 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 substances emitted from combustion engines are:

- Total Volatile Organic Compounds (TVOCs)
- carbon monoxide (CO)
- oxides of nitrogen (NO_x)
- Particulate matter less than 2.5 µm in aerodynamic diameter ($PM_{2.5}$)
- Particulate matter less than 10 µm in aerodynamic diameter (PM_{10})
- sulfur dioxide (SO_2).

Other substances 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.

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 5.4.2.1.

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 substance emissions. This default should be used only if no other available emission reduction efficiency estimation is available.

3.2 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.

3.3 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, and
- unintentional leaks and spills.

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.

4 Threshold calculations

The NPI has six different threshold categories and each NPI substance has at least one reporting threshold.

The thresholds for substances that are expected to be most commonly triggered from the use of combustion engines are Category 2a (combustion of greater than 400 tonnes of fuel) and/or Category 2b (combustion of greater than 2,000 tonnes of fuel).

You must remember that threshold calculations are based on facility wide activities. For instance, your facility may only combust 20 tonnes of diesel per year in internal combustion engines. However, 5,000 tonnes of fuel oil is combusted in a stationary boiler. Therefore, for your facility, the category 2b threshold has been triggered and emissions of all category 2a and 2b substances from all facility sources are required to be estimated and reported to the NPI. This includes emissions from the internal combustion engines that are used on-site.

The NPI reporting thresholds are defined in the *NPI Guide*. The Category 2a and 2b reporting thresholds most relevant to combustion engines are provided below for your convenience.

Category 2a substances and thresholds
This category contains a group of substances that are common products of combustion or other thermal processes. The NPI reporting thresholds for this category are:

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

Category 2a NPI substances:

- carbon monoxide
- fluoride compounds
- hydrochloric acid
- oxides of nitrogen
- Particulate matter (2.5 micrometres or less in diameter)
- Particulate matter (10 micrometres or less in diameter)
- polycyclic aromatic hydrocarbons (as B[a]Peq)
- sulfur dioxide
- Total Volatile Organic Compounds (TVOCs).

Category 2b substances and thresholds
This category also contains substances that are common products of combustion or other thermal processes and includes all Category 2a substances. It also includes metals and compounds emitted when fuels (especially coal and oil) are burnt. The NPI thresholds for this category of substances are:

- burning 2,000 tonnes or more of fuel or waste in the reporting year;
- consuming 60,000 megawatt hours or more of electrical energy for other than lighting or motive purposes in the reporting year;
- a facility that has maximum potential power consumption of 20 megawatts or more for other than lighting or motive purposes in the reporting year.

Category 2b NPI substances:

- arsenic and compounds
- beryllium and compounds
- cadmium and compounds
- carbon monoxide
- chromium (III) compounds
- chromium (VI) compounds
- copper and compounds
- fluoride compounds
- lead and compounds
- magnesium oxide fume
- mercury and compounds
- nickel and compounds
- oxides of nitrogen
- Particulate matter (2.5 micrometres or less in diameter)
- Particulate matter (10 micrometres or less in diameter)
- polychlorinated dioxins and furans (as TEQs)
- polycyclic aromatic hydrocarbons (as B[a]Peq)
- sulfur dioxide
- Total Volatile Organic Compounds (TVOCs).

If your facility trips any of the Category 2 thresholds you must estimate and report any emissions of the substances listed under these categories. Note that emissions from all sources, not just combustion sources, need to be estimated (with the exception of $PM_{2.5}$).

Transfers of Category 2 substances are not reportable. However, many Category 2 substances are also Category 1 or Category 1b substances. If the Category 1 or 1b threshold has been exceeded in its own right then transfers to mandatory transfer destinations must be reported.

The following flowchart (Figure 4.1) outlines the process for determining whether your facility has tripped the Category 2a and/or the Category 2b reporting thresholds. You should work through the steps shown in Figure 4.1 to determine whether the facility has tripped a threshold.

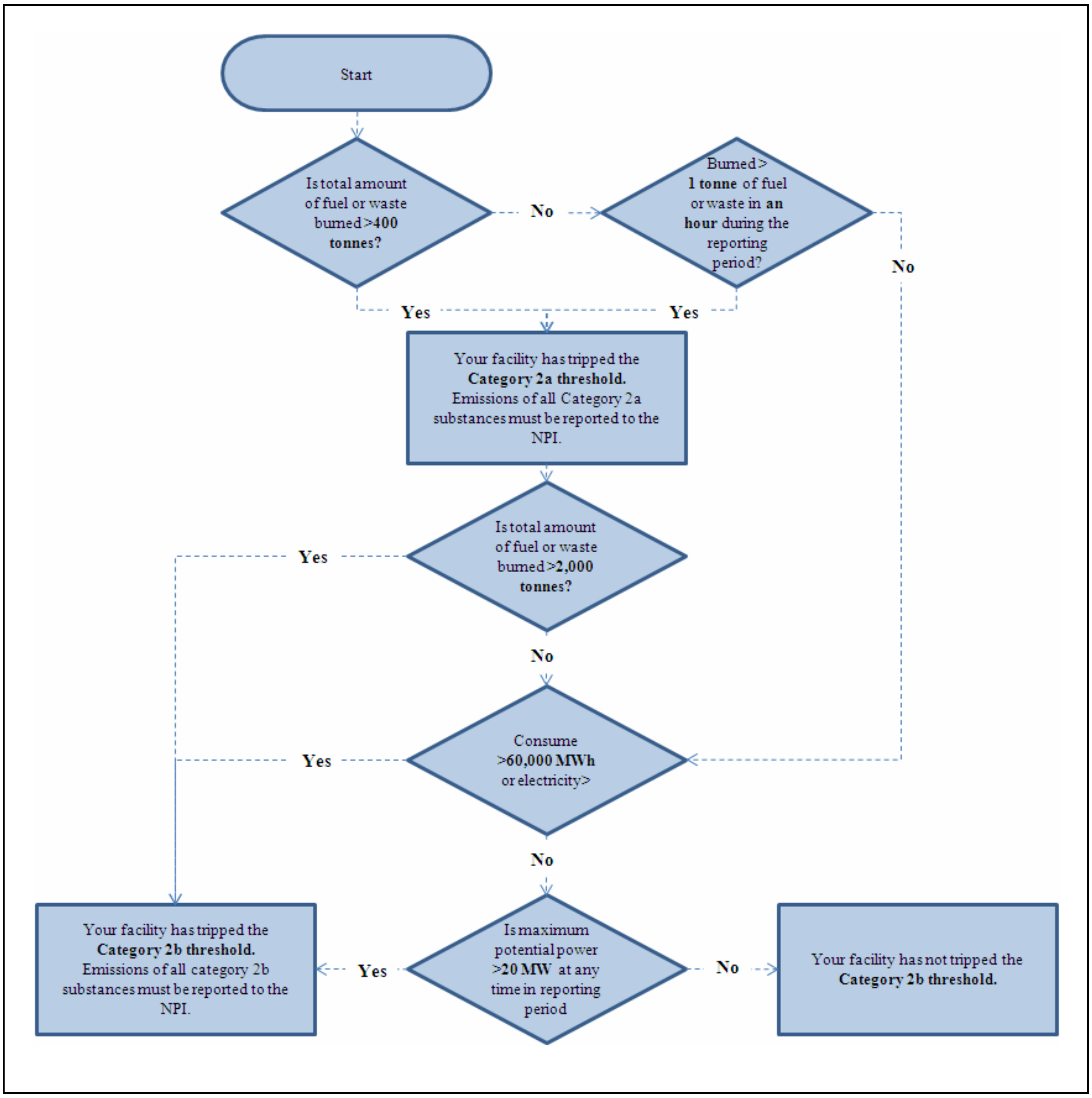


Figure 4.1: Determining whether the Category 2a and Category 2b reporting thresholds have been tripped

5 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 intended to be used in conjunction with this manual.

If you have established under Section 4 whether the quantity of fuel and/or power, used by the facility exceeds NPI thresholds, you will need to estimate the total mass of NPI substances emitted.

In general, there are four types of emission estimation techniques (EETs) described in this section that may be used to calculate emissions from your facility. These are:

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

Select the EET (or mix of EETs) that is most appropriate for your purposes. For example, you might choose direct measurement to estimate NO_x and CO emissions and emission factors to estimate all other emissions from stationary engines.

Generally, industries estimate emissions from combustion engines by using emission factors.

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

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

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (e.g. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, i.e. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed immediately (within 24 hours) during clean up operations.

5.1 Direct measurement

You may wish to use direct measurement for reporting to the NPI, particularly if you already do so in order to meet other regulatory requirements. If this is the case, the NPI does not require you to undertake additional sampling and measurement, rather simply reporting the emissions will be adequate.

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.

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)[2]	CO EF[1] (kg/kg fuel)	CO/CO_2 ratio (vol/vol)
$1.00x10^{+02}$	$1.80x10^{-03}$	$9.42x10^{-04}$
$5.00x10^{+02}$	$8.99x10^{-03}$	$4.73x10^{-03}$
$1.00x10^{+03}$	$1.80x10^{-02}$	$9.51x10^{-03}$
$2.00x10^{+03}$	$3.60x10^{-02}$	$1.92x10^{-02}$
$5.00x10^{+03}$	$9.01x10^{-02}$	$4.95x10^{-02}$
$1.00x10^{+04}$	$1.81x10^{-01}$	$1.04x10^{-01}$
$1.50x10^{+04}$	$2.72x10^{-01}$	$1.66x10^{-01}$
$2.00x10^{+04}$	$3.63x10^{-01}$	$2.35x10^{-01}$
$4.00x10^{+04}$	$7.33x10^{-01}$	$6.24x10^{-01}$

Notes:
1. EF – emission factor.
2. 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.

5.1.1 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 estimation of the contribution that each process condition makes to the overall substance emission. You should be aware that a state or territory licence condition may require tests to be conducted under maximum operating capacity where emissions are likely to be higher than when operating under normal operating conditions.

5.1.2 Continuous Emission Monitoring System (CEMS) data

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

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 emission estimation.

5.2 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 substance on the NPI, but it is often a difficult technique to apply to combustion engines.

5.3 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 substance 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 5.3.1 and Example 1 below.

5.3.1 Fuel analysis method for estimation of SO_2

Fuel analysis is a method that uses a physical property of a substance and is based on application of the mass conservation relationship. The method relies on knowing or estimating the amount of fuel used and the concentration of the substance within the fuel (in this case the fuel sulfur content). Other substances where this technique may be useful to estimate substance emission levels are fuel contaminants such as lead and fluoride. The basic equation used in fuel analysis emission calculations is the following:

$$E_i = Q_f \times \left(\frac{C_f}{100}\right) \times \left(\frac{MW_p}{EW_f}\right) \times OpHrs \qquad \text{Equation 1}$$

where:

E_i	=	Emission of substance i	(kg/y)
Q_f	=	Quantity of fuel (f) combusted in the reporting period	(kg/h)
C_f	=	Concentration of substance within fuel (f) that leads to substance release	(wt% of fuel)
MW_P	=	Molecular weight of substance emitted	(g/mole)
EW_f	=	Elemental weight of substance in fuel (f)	(g/mole)
OpHrs	=	Operating hours of engine in the reporting period	(h/y)

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 emissions

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

Q_f	=	20,900	kg/h
C_f	=	0.117	wt% of S
MW_P	=	64	g/mole
EW_f	=	32	g/mole
OpHrs	=	1,500	h/y

E_{SO2} = Q_f * (C_f/100) * (MW_P/ EW_f) * OpHrs
= 20,900 * (0.117/100) * (64/32) * 1,500
= 73,359 kg/y

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 C.

5.3.2 Fuel analysis method for estimation of fluoride

To estimate emissions of fluoride compounds from fuel analysis data, it is assumed that all fluoride present in the fuel combusted is released as hydrogen fluoride. The following equation can be used to estimate emissions of fluoride compounds from fuel combustion:

$$E_{HF} = Q_f \times C_f \times \rho \times \frac{MW_p}{EW_f} \times \frac{1}{1000}$$ Equation 2

where:

E_{HF}	=	Emission of hydrogen fluoride	(kg/y)
Q_f	=	Quantity of fuel (f) combusted in the reporting period	(m^3/y)
C_f	=	Concentration of fluoride within fuel (f) that leads to substance release	(ppm)
ρ	=	Density of fuel combusted	(kg/L)
MW_P	=	Molecular weight of substance emitted (molecular weight of hydrogen fluoride is 19 g/mole)	(g/mole)
EW_f	=	Elemental weight of substance in fuel (f) (molecular weight of fluoride is 18 g/mole)	(g/mole)

Emission factors for fluoride compounds from fuel combustion are presented in Appendix B of this manual. All fluoride compound emission factors are presented as zero, as the concentration of fluoride in fuel is unknown. However, if the concentration of fluoride in fuel is known for your facility, emissions should be estimated and reported to the NPI using Equation 2.

5.4 Emission factors

For combustion engines, emission factors relate to the quantity of substance emitted from an engine to its power or fuel consumption and, for 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 substance per kWh, factors based on fuel usage are kg of substance per m^3 of fuel and factors based on distance travelled are kg of substance per km travelled in the reporting year. For combustion engines described in this manual the fuel is either liquid or gas. The emission factors provided are from Australian sources unless otherwise stated.

Equation 3 is the general equation for the use of an emission factor to estimate annual substance release and is common to all NPI manuals using emission factor techniques. Equations 4, 5, 6, 7 and 9 show the use of emission factors for combustion engines to estimate the substances emitted for combustion engines in different situations.

$$E_i = A \times EF_i \times \left(\frac{100 - ER_i}{100} \right)$$ Equation 3

where:

E_i	=	Emission of substance i	(kg/y)
A	=	Activity rate (quantity of fuel combusted in the reporting period)	(kL/y)
EF_i	=	Emission factor of substance i	(kg/kL)
ER_i	=	Emission reduction efficiency for substance i	(%)

Emission factors developed by industry from specific process measurements may also be used to estimate emissions. These specific emission factors can be applicable to a number of processes similar in operation and size. However, it is required that industry developed emission factors be 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. Substance emissions from vehicles while used off-site are included in area based emission estimates performed periodically by the relevant state or territory environment agencies. EETs are provided for vehicles powered by combustion engines and used on-site (within the facility boundary).

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.

This manual provides emission factors for:

- road transport vehicles (Section 5.4.1.1 and Table 2);
- industrial vehicles (Section 5.4.1.2 and Table 3); and
- stationary engines (Section 5.4.2 and Table 4).

Table 2: Emission factor summary for road transport vehicles

Engine type	Fuel	Table	Substances	Units
Passenger car	Diesel	Table 9	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs.	kg/m³
	Petrol	Table 10	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
	Petrol	Table 11	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/km
	LPG	Table 12	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/km
	LPG	Table 13	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
	E10	Table 14	CO, Fluoride compounds, NOx, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
LGV[1]	Diesel	Table 15	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
	Petrol	Table 16	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/km
	Petrol	Table 17	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
	LPG	Table 18	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/km
	LPG	Table 19	Benzene, 1,3 Butadiene, CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
MGV[2]	Diesel	Table 20	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
HGV[3]	Diesel	Table 21	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
Very HGV[4]	Diesel	Table 22	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
Bus[5]	Diesel	Table 23	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
Buses and trucks	Natural gas	Table 24	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
Forklift	LPG	Table 25	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³

1. LGV is light goods vehicle ≤ 3.5 t GVM.
2. MGV is medium goods vehicle < 3.5 t GVM ≤ 12 t.
3. HGV is heavy goods vehicle <12 t GVM ≤ 25 t.
4. Very HGV is heavy goods vehicle >25 t GVM.
5. Bus is heavy bus >5 t GVM.

Table 3: Emission factor summary for industrial vehicles

Engine type	Fuel	Table	Substances	Units
Track-type tractor	Diesel	Table 26	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Wheeled tractor	Diesel	Table 27	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Wheeled dozer	Diesel	Table 28	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Scraper	Diesel	Table 29	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Motor grader	Diesel	Table 30	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Wheeled loader	Diesel	Table 31	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Track-type loader	Diesel	Table 32	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Off-highway truck	Diesel	Table 33	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Roller	Diesel	Table 34	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Miscellaneous	Diesel	Table 35	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
Wheeled tractor	Petrol	Table 36	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh and kg/h
Motor grader	Petrol	Table 37	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh and kg/h
Wheeled loader	Petrol	Table 38	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh and kg/h
Roller	Petrol	Table 39	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh and kg/h
Miscellaneous	Petrol	Table 40	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh and kg/h
Miscellaneous industrial	LPG	Table 41	CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kg LPG

Table 4: Emission factor summary for stationary engines

Engine type	Fuel	Control	Table	Substances	Units
Engines greater than 450 kW	Diesel	NA	Table 42	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
	Diesel	NA	Table 43	Acetaldehyde, Benzene, CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Toluene, TVOCs, Xylenes	kg/m³
	Dual Fuel (Diesel/Waste Oil)	NA	Table 44	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
	Dual Fuel (Diesel/Waste Oil)	NA	Table 45	Acetaldehyde, Benzene, CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Toluene, TVOCs, Xylenes	kg/m³
	Dual Fuel (95%NG/5% Diesel)	NA	Table 46	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2 TVOCs	kg/kWh
	Dual Fuel (95%NG/5% Diesel)	NA	Table 47	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/m³
	Dual Fuel (90%NG/10% Diesel)	NA	Table 48	Benzene, CO, Ethylbenzene, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs, Toluene, Xylenes	kg/m³
Engines less than 450 kW	Diesel	NA	Table 49	CO, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs	kg/kWh
	Diesel	NA	Table 50	Acetaldehyde, Benzene, 1,3-Butadiene, CO, Fluoride compounds, Formaldehyde, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, TVOCs, Toluene, Xylenes	kg/m³
Gas turbines	Natural gas	Uncontrolled	Table 51	Acetaldehyde, Acrolein, Benzene, 1,3-Butadiene, CO, Ethylbenzene, Fluoride compounds, Formaldehyde, NOx, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Toluene, TVOCs, Xylenes	kg/Nm³
	Natural gas	Uncontrolled	Table 52	Acetaldehyde, Acrolein, Benzene, 1,3-Butadiene, CO, Ethylbenzene, Fluoride compounds, Formaldehyde, NOx, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Toluene, TVOCs, Xylenes	kg/kWh
2-stroke engines	Natural gas	Uncontrolled/ lean burn	Table 53	Acetaldehyde, Acrolein, Benzene, 1,3-Butadiene, Chloroform, CO, Dichloroethane, Ethylbenzene, Fluoride compounds, Formaldehyde, n-Hexane, Methanol, NO_x,	kg/m³

Engine type	Fuel	Control	Table	Substances	Units
				Phenol, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Styrene, Toluene, Vinyl chloride monomer, TVOCs, Xylenes	
4-stroke lean burn engines	Natural gas	Uncontrolled	Table 54	Acetaldehyde, Benzene, Biphenyl, 1,3-Butadiene, Chloroethane, Chloroform, CO, Dichloroethane, Ethylbenzene, Fluoride compounds, Formaldehyde, n-Hexane, Methanol, NO_x, Phenol, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Styrene, Toluene, Vinyl chloride monomer, TVOCs, Xylenes	kg/m³
	Biogas	Uncontrolled	Table 55	CO, Fluoride compounds, NO_x, PAHs, SO_2	kg/Nm³
	Biogas	Uncontrolled	Table 56	CO, Fluoride compounds, NO_x, PAHs, SO_2	kg/kWh
4-stroke rich burn engines	Natural gas	Uncontrolled	Table 57	Acetaldehyde, Benzene, 1,3-Butadiene, Chloroform, CO, Dichloroethane, Ethylbenzene, Fluoride compounds, Formaldehyde, Methanol, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Styrene, Toluene, Vinyl chloride monomer, TVOCs, Xylenes	kg/m³
Gas turbines	Landfill gas	Uncontrolled	Table 58	Acetonitrile, Benzene, Chloroform, CO, Dichloromethane, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Tetrachloroethane, Trichloroethylene, Toluene, TVOCs, Vinyl chloride, Xylenes.	kg/m³
	Landfill gas	Uncontrolled	Table 59	Acetonitrile, Benzene, Chloroform, CO, Dichloromethane, Fluoride compounds, NO_x, $PM_{2.5}$, PM_{10}, PAHs, SO_2, Tetrachloroethane, Trichloroethylene, Toluene, TVOCs, Vinyl chloride, Xylenes.	kg/kWh

5.4.1 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-site use is vehicles used within a mine site or petrochemical plant. If a vehicle is used both on-site and off-site, only the on-site emissions are estimated by the facility and reported to the NPI.

The EETs for vehicles provide methods for estimating emissions of CO, NO_x, PM_{10}, SO_2, TVOCs and other NPI reportable substances. The parameters required to estimate the substance 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. Emission estimates for these are 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 on engine power (Equation 5) 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 7) and requires the following two factors to be known:

- 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, vehicles commonly 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 D.

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, depending on the characteristics of the engine, use the various stationary engine emission factors from Appendix B.

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.

5.4.1.1 Road-transport vehicles

To estimate emissions from road-transport vehicles, the vehicle type and distance travelled by the vehicle are required.

$$E_i = L_Y \times EF_i \qquad \text{Equation 4}$$

where:

E_i	=	Emission of substance i for a specific engine type	(kg/y)
L_Y	=	Distance travelled in reporting year	(km/y)
EF_i	=	Emission factor of substance i, for given engine and fuel type	(kg/km)
i	=	Substance i	(-)

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.

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

The emission factors for the light goods vehicle, heavy goods vehicle (HGV), bus and motorcycle categories of road-transport vehicles are listed in Appendix B.

5.4.1.2 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 5 estimates emissions for individual industrial vehicles based on engine power using the emission factors from Appendix B and the load factors in Table 5.

$$E_i = P \times OpHrs \times LF \times EF_i \qquad \text{Equation 5}$$

where:

E_i	=	Emission of substance i for a specific engine type	(kg/y)
P	=	Average rated engine power	(kW)
OpHrs	=	Vehicle operating hours	(h/y)
LF	=	Load factor utilised in facility operations for equipment type	(-)
EF_i	=	Emission factor of substance i, for given engine and fuel type	(kg/kWh)
i	=	Substance i	(-)

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 C and further conversion factors can be obtained from many sources, e.g. Reference 17.

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. Also a less accurate alternative is an estimate based on distance travelled as outlined in Section 5.4.1.1. Another less accurate method is to estimate hours over a period of time and extrapolate these data 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 substance emissions is not specifically in Table 5, use the LF for equipment that is similar or use the default LF of 0.5.

For petrol powered industrial vehicles VOC emissions occur from exhaust and also from evaporation and the crankcase. The evaporative and crankcase VOC emissions are dependent only on the hours of operation and can be estimated by Equation 6 below. Emission factors (in kg/h) for Equation 6 are listed in Appendix B.

$$E_i = OpHrs \times EF_i \qquad \text{Equation 6}$$

where:

E_i	=	Emission of substance i for a specific engine type	(kg/y)
OpHrs	=	Vehicle operating hours	(h/y)
EF_i	=	Emission factor of substance i, for given engine and fuel type	(kg/h)
i	=	Substance i	(-)

Equation 7 estimates emissions for individual industrial vehicles based on fuel consumption using the emission factors listed in Appendix B and the load factors in Table 5.

$$E_i = Q_f \times LF \times EF_i \qquad \text{Equation 7}$$

where:

E_i	=	Emission of substance i for a specific engine type	(kg/y)
Q_f	=	Quantity of fuel combusted during the reporting year	(kg /y or L/y)
LF	=	Load factor utilised in facility operations for equipment type	
EF_i	=	Emission factor of substance i, for given engine and fuel type	(kg/L or kg/kg)
i	=	Substance	(-)

The total VOC emissions are obtained from summing exhaust VOC emissions derived from Equation 5 or Equation 7 and evaporative and crankcase emissions derived from Equation 6.

Steps for estimating vehicle emissions

The five steps to estimate the quantity of substances emitted from combustion engine powered vehicles are given below:

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 C.

The load factor is obtained from Table 5. 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 Equation 8.

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.

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 VOC emissions are included as part of the total VOC emissions from the vehicle. The VOC emissions from evaporation and crankcase sources depend 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.

Table 5: 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
Notes: [1] Used on rough terrain, steep grades or poorly graded tracks	

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 8 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.

$$OpHrs = OpHrs_p \times \frac{L_Y}{L_P} \qquad \text{Equation 8}$$

where:

$OpHrs$	=	Operating hours for vehicle in the reporting year	(h/y)
$OpHrs_P$	=	Operating hours for vehicle for typical period of operation of at least 4 weeks	(h/period)
L_Y	=	Distance travelled in reporting year	(km/y)
L_P	=	Distance travelled for typical period of operation	(km/period)

Example 2 illustrates the application of Equation 5 using a load factor from Table 5 and emission factors from Table 27. All data inputs are described.

Example 2– Calculating petrol and diesel engine vehicle emissions

For this example, emissions are estimated for a 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 hp = 78 hp*0.7456kW/hp = 58kW

ii) From Table 5 the load factor for a tractor is 0.55.

Step 3

Determine operating 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 1,021 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 petrol industrial vehicle from Appendix B and calculate emissions. The reportable emissions are in the right column in step 5 below.

Emissions are calculated below using Equation 5.

Substance i	Power (kW)		Operating hours (h/y)		Emission factor (kg/kWh)		Load factor (-)	=	Emissions (kg/y)
	P	x	OpHrs	x	EF_i	x	LF	=	E_i
CO	58	x	1,021	x	$1.90x10^{-01}$	x	0.55	=	$6.19x10^{+03}$
Formaldehyde	58	x	1,021	x	$3.41x10^{-04}$	x	0.55	=	$1.11x10^{+01}$
NO_x	58	x	1,021	x	$8.54x10^{-03}$	x	0.55	=	$2.78x10^{+02}$
PM_{10}	58	x	1,021	x	$4.84x10^{-04}$	x	0.55	=	$1.58x10^{+01}$
SO_2	58	x	1,021	x	$3.04x10^{-04}$	x	0.55	=	$9.90x10^{+00}$
TVOCs - engine	58	x	1,021	x	$7.16x10^{-03}$	x	0.55	=	*$2.33x10^{+02}$*
TVOCs – evaporative			1,021	x	$3.09x10^{-02}$			=	*$3.15x10^{+01}$*
TVOCs - crankcase			1,021	x	$3.26x10^{-02}$			=	*$3.33x10^{+01}$*
TVOCs – total								=	$2.98x10^{+02}$

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

Example 3 shows emission estimation from 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
10 kL of diesel fuel was combusted in on-site diesel utility/light trucks in the NPI reporting year. It is estimated that 25% of operation 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 substance emissions.

Step 2
Determine the volume of diesel fuel combusted.

The volume of diesel combusted in the reporting year was 10 m³ (10 kL)

Step 3
Select the appropriate EF values for the vehicle and calculate emissions. The emission factors are those for a diesel light goods vehicle (LGV) sourced from Table 20.

Emissions calculated for the vehicle using Equation 3 are:

Substance (i)	Fuel used (kL/y)		Emission factor (diesel LGV) (kg/kL)		Emissions (kg/y)
	Q_f	x	EF	=	E_i
CO	10	x	$1.94x10^{+01}$	=	$1.94x10^{+02}$
NO_x	10	x	$8.89x10^{+00}$	=	$8.89x10^{+01}$
$PM_{2.5}$	10	x	$2.34x10^{+00}$	=	$2.34x10^{+01}$
PM_{10}	10	x	$2.39x10^{+00}$	=	$2.39x10^{+01}$

5.4.2 Emission estimates from stationary combustion engines

Estimating emissions of CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 and TVOCs 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 substances other than CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2 and TVOCs, emissions have to be estimated with the fuel-input technique.

The emission factors for stationary engines are listed in Appendix B. A wide variety of engines is covered in these tables; the criteria used to differentiate the engines are usually fuel type and engine size. The emission factor tables can be used for a wide range of stationary combustion engine powered equipment, such as compressors and pumps, 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 6 and their fitment can be determined by examining either the owner's manual for the engine or the engine's records.

Large natural gas engines are used for electricity production and in the natural gas industry to compress and transport natural gas. The emission factors listed include the emission factors for natural gas engines of various types using different types of emission control techniques.

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.

5.4.2.1 Engine power method to estimate emissions from stationary combustion engines

Emission factors are chosen from Appendix B based on engine power, fuel type and pollution control equipment fitted and, for natural gas engines, the type of engine. The estimation technique used is similar to that described in Section 5.4.1 for combustion engine powered industrial vehicles, except the second step is different: instead of LF, the emission reduction efficiency of any pollution control equipment is determined. Total substance emissions from a stationary combustion engine can be estimated by applying Equation 9.

$$E_i = P \times OpHrs \times EF_i \times \left(\frac{100 - ER_i}{100} \right) \qquad \text{Equation 9}$$

where:

E_i	=	Total emission of substance i from a stationary combustion engine for the NPI reporting year	(kg/y)
P	=	Engine power capacity rating	(kW)
OpHrs	=	Operating hours of engine during the NPI reporting year	(h/y)
EF_i	=	Emission factor of substance i	(kg/kWh)
ER	=	Emission reduction efficiency for substance i	(%)
i	=	Substance i	(-)

Be aware that emission reduction efficiency (ER) is not the same for all substances emitted from a combustion engine. Typically emission reduction focuses on NO_x emissions (see Table 7) and in some cases particulate matter (PM_{10}).

Engine operating hours (OpHrs) is a critical aspect of estimating the substance 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 substances 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 it can be converted to kW using 1hp = 0.7456 kW. Other useful conversion factors are in Appendix C.

Step 2
Determine the ER factors for various substances 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 substances emitted. As outlined in Section 3.1 and Table 6 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 (5.4.2.1).

Step 4
Select the appropriate EF values from Appendix B.

This will depend on the type of engine and can be obtained from the appropriate table in Appendix B. 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 9.

Example 4– Calculating stationary engine emissions – engine power technique
This example illustrates the steps for estimating substance emissions from a 250 kW diesel engine used for 3,650 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

Step 2
Determine the ER factors for various substances 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.

3,650 h, for the reporting year examined.

Step 4
Select the appropriate EF values from Appendix B for a diesel engine of less than 450 kW.

Step 5
Calculate substance emissions using Equation 9.

Substance (i)	Power (kW) P		Operating hours (h/y) OpHrs		Emission factor (kg/kWh) EF_i		Fraction released (100-ER)/100	=	Emissions (kg/y) E_i
		x		x		x		=	
CO	250	x	3,650	x	$4.06x10^{-03}$	x	1.0	=	$3.70x10^{+03}$
NO_x	250	x	3,650	x	$1.88x10^{-02}$	x	0.8	=	$1.37x10^{+04}$
$PM_{2.5}$	250	x	3,650	x	$1.31x10^{-03}$	x	0.1	=	$1.20x10^{+02}$
PM_{10}	250	x	3,650	x	$1.34x10^{-03}$	x	0.1	=	$1.22x10^{+02}$
SO_2	250	x	3,650	x	$1.25x10^{-03}$	x	1.0	=	$1.14x10^{+03}$
TVOCs	250	x	3,650	x	$1.37x10^{-03}$	x	1.0	=	$1.25x10^{+03}$

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 Equation 10) is best used.

Fuel consumption method to estimate 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 substance.

Total substance emissions from a stationary combustion engine can be estimated by applying Equation 10.

$$E_i = Q_f \times EF_i \times \left(\frac{100 - ER_i}{100} \right) \qquad \text{Equation 10}$$

where:

E_i	=	Total emission of substance i from an engine	(kg/y)
Q_f	=	Quantity of fuel combusted during the reporting year	(m^3/y)
EF_i	=	Emission factor of substance i	(kg/m^3 fuel)
ER	=	Emission reduction efficiency for substance i	(%)
i	=	Substance i	(-)

Be aware that emission reduction efficiency (ER) is not the same for all substances emitted from a combustion engine. Typically emission reduction focuses on NOx emissions (see Table 6) and in some cases particulate matter (PM_{10}).

The five steps to estimate the quantity of substances 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 listed in Appendix C.

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 Appendix C. Equation 11 can be used to convert fuel weight to fuel volume.

$$F = \frac{FW}{\rho}$$ Equation 11

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)
ρ	=	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 12.

Step 2
Determine the ER factors for various substances 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 substances to be reported. As outlined in Section 3.1 and Table 6 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 (Appendix B). The engine power is used to determine which emission factor table to use to look up emission factors, not to estimate substance emissions directly.

Step 4
Select the appropriate EF values.

These are obtained from emission factors listed in Appendix B, depending on the information gathered in Step 3 above.

Step 5
Calculate emissions using Equation 10.

Example 5 illustrates the application of Equation 10 using the emission factors from Appendix B. Other data required are 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 m3 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 substances 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 appropriate table in Appendix B.

Step 5
Calculate emissions using Equation 10.

Substance (i)	Fuel usage (m^3/y) F		Emission factor (kg/m^3) EF_i		Fraction released (100-ER)/100		Emissions (kg/y) E_i
		x		x		=	
CO	300	x	$1.56x10^{+01}$	x	1	=	$4.68x10^{+03}$
NO_x	300	x	$7.25x10^{+01}$	x	0.2	=	$4.35x10^{+03}$
$PM_{2.5}$	300	x	$4.98x10^{+00}$	x	0.1	=	$1.49x10^{+02}$
PM_{10}	300	x	$5.10x10^{+00}$	x	0.1	=	$1.53x10^{+02}$
SO_2	300	x	$4.77x10^{+00}$	x	1	=	$1.43x10^{+03}$
TVOCs	300	x	$5.30x10^{+00}$	x	1	=	$1.59x10^{+03}$

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5.4.2.2 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 12.

$$F = F_P \times \frac{OpHrs_Y}{OpHrs_P}$$

Equation 12

where:

F	=	Fuel used for the NPI reporting year	(m^3/y)
F_P	=	Fuel used for typical period of engine operation	(m^3)
$OpHrs_Y$	=	Engine operating hours for reporting year	(h/y)
$OpHrs_P$	=	Time of typical period of engine operation	(h)

If all the stationary combustion engines at the facility 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 6 and Table 7 provide further detail of the emission reduction equipment and emission control technologies available for combustion engines.

Table 42 to Table 48 provide emission factors for large (greater than or equal to 450 kW) stationary diesel engines and Table 49 to Table 50 provide emission factors for small (less than 450 kW) stationary diesel engines.

5.4.3 Control technologies

Table 6 summarises whether the various diesel emission reduction technologies, some of which may also be applicable to petrol engines, will generally increase or decrease the substance emissions. These technologies are categorised according to:

- fuel modifications;
- engine modifications; and
- after-exhaust treatment.

Current data is insufficient to quantify the results of these modifications, but Table 6 provides details of the resultant trends with regard to substance emissions.

For large combustion engines (>450kW), control measures to date have been directed towards reducing NO_x emissions, since NO_x is the primary substance from diesel and dual-fuel engines. Table 7 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 substance 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 7 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 1, 3 and 11) is 9,896 kJ/kWh (7,000 BTU/hp-h).

If a fuel has 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. 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 13. The energy content values used in Equation 13 (HV_1 and HV_2) need to have the same units.

$$EF_1 = EF_2 \times \frac{EC_1}{EC_2} \qquad \text{Equation 13}$$

where:

EF_1	=	New EF for fuel with different energy content	
EF_2	=	Old EF for fuel with initial energy content	
EC_1	=	Energy content (heat value) of new fuel (see fuel specifications from supplier)	(MJ/L or MJ/kg)
EC_2	=	Energy content (heat value) of original fuel (see table where EF_2 is obtained)	(MJ/L or MJ/kg)

Table 6: Diesel engine emission control technologies[1]

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}, NO_x, TVOCs

Notes:

1. Source: Reference 3, Table 3.3-3.

Table 7: NO_x reduction and fuel consumption penalties for large stationary diesel and dual-fuel engines[1]

Control approach	Diesel		Dual-fuel	
	NOx reduction [2] (%)	ΔBSFC[3] (%)	NOx reduction[2] (%)	ΔBSFC[3] (%)
Derate				
10%	ND[4]	ND[4]	<20	4
20%	<20	4	ND[4]	ND[4]
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[4]	ND[4]	<20	0
± 10%	7-8	3	25-40	1-3
Water injection (H_2O/fuel ratio)				
50%	25-35	2-4	ND[4]	ND[4]
Selective catalytic reduction	80-95	0	80-95	0

Notes:

1. Source: Reference 1, 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.

5.5 Approved alternative

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

6 Transfers of NPI substances in waste

The NPI requires the mandatory reporting of NPI substances that are transferred in waste to a final destination. Transfers are required to be reported if a Category 1, Category 1b or Category 3 reporting threshold is exceeded. For example, if the threshold has been exceeded for 'lead and compounds' (Category 1 substance) as a result of use of this substance on-site, transfers to final destination of lead and its compounds as well as the emissions are reportable. Both emissions and transfers are reportable in kilograms.

There is no requirement to report transfers of substances that are exclusively Category 2a or 2b in the event that they have been tripped only by the fuel and energy use threshold (i.e. there is no requirement to report transfers of oxides of nitrogen, particulate matter ≤ 10 µm (PM_{10}), particulate matter ≤ 2.5 µm ($PM_{2.5}$), polychlorinated dioxins and furans, or polycyclic aromatic hydrocarbons). Transfers are also not reportable if they are contained in overburden, waste rock, uncontaminated soil or rock removed in construction or road building, or soil used in capping of landfills.

Reporting of transfers is, however, required if wastes are transported to a destination for containment or destruction which includes:

- a destination for containment including landfill, tailings storage facility, underground injection or other long term purpose-built waste storage facility
- an off-site destination for destruction
- an off-site sewerage system, and
- an off-site treatment facility which leads solely to one or more of the above.

A containment destination may be on-site, for example a tailing storage facility on a mine site, or off-site, for example waste going to landfill. The transport or movement of substances contained in waste to a sewerage system is also included.

In the specific context of combustion engines, the quantities of NPI substances contained in spent (or contaminated, waste) diesel, petrol, natural gas will need to be reported as a transfer if a threshold has been tripped.

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

Further information regarding transfers of waste, including how to estimate and report, can be found in the *NPI Guide*.

7 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 substance emissions from combustion engines. The selected technique will depend on available data and resources. The EET used will affect the degree of accuracy attained for the substance emission estimate. In general, site-specific data representative of normal operations is more accurate than industry-averaged data (such as the emission factors in Section 3.4 in this manual).

7.1 Direct measurement

The use of stack and/or workplace health and safety sampling data is likely to be a more accurate method of estimating substance 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 substance emissions.

For data to be representative the sampling used for NPI reporting needs to be conducted over a significant period of time and cover all substance 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 substance emission prone to large errors. However, it may be misleading to assert that a snapshot, such as stack sampling, can better predict long-term substance emission than CEMS. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and to ensure the substance emission data is representative of substance emissions from the facility.

7.2 Mass balance

Calculating substance 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, substance 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 substance emission estimates of low accuracy.

For example the generic reaction in fuel combustion is as follows:

$$Fuel + Air \rightarrow Water + CO_2 + Pollutants$$

The sum of the substances emitted is typically less than 2wt% of the fuel combusted, whereas, the CO_2 emitted is approximately 95wt% of the fuel combusted. If an error of +/-5% is made in determining CO_2 emissions, the error in the sum of the substances emitted is significant.

There are exceptions for some substances released from fuel combustion, such as SO_2 and hydrogen fluoride. If the substance concentration (e.g. sulfur or fluoride) in the fuel combusted is accurately known, then a mass balance approach will result in emission estimates of high accuracy.

7.3 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 substance emission levels. However, the theoretical equations and models are often not developed to the stage where substance 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 substance emissions.

7.4 Emission factor rating and accuracy

When using emission factors, you should be aware of the associated emission factor rating (EFR) code and what the rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor and the target equipment/process from which the factor was derived.

The EFR system is:

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

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

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

8 Next steps for reporting

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

- Combustion in boilers
- Fuel and organic liquid storage
- Fugitive emissions.

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

9 References

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Appendix A: Definitions and abbreviations

Table 8: Glossary of technical terms and abbreviations used in this manual

Term	Definition
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. (Note: In this manual the emission factors are often in terms of kg/kW. To convert to kW use the factor 1 hp = 0.7456 kW).
BSFC	Brake-specific fuel consumption
CEMS	Continuous emission monitoring systems
CNG	Compressed natural gas
CO	Carbon monoxide
EC	Energy content of fuel (also called heat value)
EEA	European Environment Agency
EET	Emission estimation technique
EF	Emission factor
EFR	Emission factor rating
E_i	Emission of substance i per year
FW	Fuel weight used in NPI reporting year
h	Hour
HGV	Heavy goods vehicle
hp	Horsepower: unit of measuring engine power.
i	Substance component whose emission level is being determined
kW	Kilowatt
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
NA	Not applicable
ND	No data
NG	Natural gas
NO_x	Oxides of nitrogen
NPI	National Pollutant Inventory
OEM	Original equipment manufacture
OpHrs	Annual operating hours for engine
PAHs	Polycyclic aromatic hydrocarbons: group of light aromatic gaseous substances released from combustion.
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 µm

Term	Definition
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 µm
Prime mover	The stationary engine which is the main supplier of force or power for a given situation
Q_f	Quantity of fuel combusted during the reporting year
QDE & H	Queensland Department of Environment and Heritage
ρ	Fuel density
SCR	Selective catalytic reduction
Sm^3	Standard cubic metres of gas, i.e. at 15°C and 1 atm pressure
SO_2	Sulfur dioxide
TNMOC	Total non-methane organic compounds
TOC	Total organic compounds
USEPA	United States Environmental Protection Agency
TVOCs	Total volatile organic compounds
y	Year

Appendix B: Emission factors

B.1 Road transport vehicles

Table 9: Emission factors (kg/m³) for diesel vehicle exhaust emissions (car)[2]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	10	$1.01x10^{+01}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	6.7	$6.69x10^{+00}$	U
Particulate matter 2.5 µm	2	$1.98x10^{+00}$	U
Particulate matter 10.0 µm	2.1	$2.08x10^{+00}$	U
Polycyclic aromatic hydrocarbons[4]	0.00032	$3.19x10^{-04}$	U
Sulfur dioxide[3]	0.017	$1.67x10^{-02}$	U
Total volatile organic compounds[5]	0.82	$8.18x10^{-01}$	U

Notes:

1. Source: Reference 2, Table 66.
2. Car consists of passenger and off road, less than or equal to 9 seats.
3. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard
4. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total hydrocarbon emission factor presented in Reference 2, Table 66, and organic speciation profile for diesel exhaust sourced from Reference 22.
5. Total VOC emission factor derived from total hydrocarbon emission factor presented in Reference 2, Table 66 and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 10: Emission factors (kg/km) for road transport vehicles - petrol cars

Substance	Emission factor[1] (kg/km)	Emission factor scientific notation (kg/km)	Rating
Benzene[3]	0.000014	1.40×10^{-05}	D
1,3 Butadiene (vinyl ethylene)[3]	0.000007	7.02×10^{-06}	D
Carbon monoxide	0.0044	4.44×10^{-03}	B
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.0008	8.00×10^{-04}	B
Particulate matter 2.5 µm[4]	0.0000075	7.45×10^{-06}	U
Particulate matter 10.0 µm[3]	0.000008	8.03×10^{-06}	D
Polycyclic aromatic hydrocarbons[5]	0.00000000060	6.00×10^{-10}	U
Sulfur dioxide[2]	0.000012	1.17×10^{-05}	D
Total volatile organic compounds	0.00029	2.92×10^{-04}	B

Notes:

1. Source: Reference 6, 7, 8, and 14.
2. Converted to kg/km based on fuel consumption of 11.06 L/100km from average of the Australian 2001 CVE (Reference 7) and the 2005 NISE (Reference 6) studies.
3. Source (Reference 8) based on g/L basis, petrol density 739 kg/kL.
4. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
5. Emission factor presented in units of kg TEQ/km. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.
6. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000007 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 11: Emission factors (kg/m³) for road transport vehicles - petrol cars

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Benzene[2]	0.12	1.17×10^{-01}	D
1,3 Butadiene (vinyl ethylene)[2]	0.059	5.90×10^{-02}	D
Carbon monoxide	37	$3.73 \times 10^{+01}$	B
Fluoride compounds[5]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	6.7	$6.73 \times 10^{+00}$	B
Particulate matter 2.5 µm[3]	0.062	6.22×10^{-02}	U
Particulate matter 10.0 µm[2]	0.067	6.70×10^{-02}	D
Polycyclic aromatic hydrocarbons[4]	0.0000052	5.17×10^{-06}	U
Sulfur dioxide[2]	0.098	9.80×10^{-02}	D
Total volatile organic compounds	2.5	$2.46 \times 10^{+00}$	B

Notes:

1. Source: Reference 8, and 14.
2. Source: Reference 8 based on g/L basis, petrol density 739 kg/kL.
3. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
4. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.
5. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 12: Emission factors (kg/km) for road transport vehicles – LPG cars[,2,3]

Substance	Emission factor[1] (kg/km)	Emission factor scientific notation (kg/km)	Rating
Benzene[4]	0	$0.00 \times 10^{+00}$	U
1,3 Butadiene (vinyl ethylene)[4]	0	$0.00 \times 10^{+00}$	U
Carbon monoxide	0.0062	6.16×10^{-03}	U
Fluoride compounds[4]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.0006	6.00×10^{-04}	U
Particulate matter 2.5 µm[4]	0	$0.00 \times 10^{+00}$	U
Particulate matter 10.0 µm[4]	0	$0.00 \times 10^{+00}$	U
Polycyclic aromatic hydrocarbons[5]	0.000000000021	2.09×10^{-11}	U
Sulfur dioxide[4]	0	$0.00 \times 10^{+00}$	U
Total volatile organic compounds	0.00072	7.22×10^{-04}	U

Notes:
1. Source: Reference 9 Table 5.20, Reference 14, profile 120.
2. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors for miscellaneous industrial vehicles.
3. Based on emissions for petrol and LPG passenger vehicles.
4. Emissions are negligible.
5. Emission factor presented in units of kg TEQ/km. Emission factor was derived from total VOC emission factor and organic speciation profile for LPG exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.

Table 13: Emission factors (kg/m³) for road transport vehicles – LPG cars[2,4]

Substance	Emission factor[1] (kg/m³)[3]	Emission factor scientific notation (kg/m³)	Rating
Benzene[5]	0	$0.00 \times 10^{+00}$	U
1,3 Butadiene (vinyl ethylene)[5]	0	$0.00 \times 10^{+00}$	U
Carbon monoxide	35	$3.50 \times 10^{+01}$	U
Fluoride compounds[5]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	3.4	$3.41 \times 10^{+00}$	U
Particulate matter 2.5 µm[5]	0	$0.00 \times 10^{+00}$	U
Particulate matter 10.0 µm[5]	0	$0.00 \times 10^{+00}$	U
Polycyclic aromatic hydrocarbons[6]	0.00000012	1.19×10^{-07}	U
Sulfur dioxide[5]	0	$0.00 \times 10^{+00}$	U
Total volatile organic compounds	4.1	$4.11 \times 10^{+00}$	U

Notes:
1. Source: Reference 7, Reference 9 Table 5.20, Reference 14, profile 120.
2. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors fro miscellaneous industrial vehicles.
3. Converted to kg/m³ using fuel consumption of 21.4 L/100km on relativity of ULP to LPG consumption for LGVs from Reference 7.
4. Based on emissions for petrol and LPG passenger vehicles.
5. Emissions are negligible.
6. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total VOC emission factor and organic speciation profile for LPG exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.

Table 14: Emission factors (kg/m³) for passenger cars operating on E10 blends

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide[2]	25.3	$2.53x10^{+01}$	B
Fluoride compounds[5]	0	$0.00x10^{+00}$	U
Oxides of nitrogen[2]	7.91	$7.92x10^{+00}$	B
Particulate matter 2.5 µm[3]	0.062	$6.22x10^{-02}$	U
Particulate matter 10.0 µm[3]	0.067	$6.70x10^{-02}$	U
Polycyclic aromatic hydrocarbons[4]	0.0000041	$4.12x10^{-06}$	U
Sulfur dioxide[3]	0.098	$9.80x10^{-02}$	U
Total volatile organic compounds[2]	1.99	$1.99x10^{+00}$	B

Notes:

1. Source: Reference 13.
2. The reductions/increases in emissions fro E10 from the APACE study (reference 13) have been applied to ULP passenger car vehicles.
3. Assuming the same emission factors as for passenger cars operating on petrol fuel as no specific data were available for E10 blend.
4. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust (assuming ADR37-01 and driving speed of 30 km/h and organic speciation profile for petrol exhaust is similar to E10 exhaust) sourced from Reference 22.
5. It is expected that all fluoride present in E10 will be emitted as hydrogen fluoride. However, the fluoride content of E10 is unknown. If the fluoride content of E10 is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in E10 fuel (ppm mass basis).

Table 15: Emission factors (kg/m³) for diesel vehicle exhaust emissions (LGV)[2]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	19	$1.94x10^{+01}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	8.9	$8.89x10^{+00}$	U
Particulate matter 2.5 µm	2.3	$2.34x10^{+00}$	U
Particulate matter 10.0 µm	2.4	$2.39x10^{+00}$	U
Polycyclic aromatic hydrocarbons[4]	0.00016	$1.65x10^{-04}$	U
Sulfur dioxide[3]	0.017	$1.67x10^{-02}$	U
Total volatile organic compounds[5]	0.42	$4.23x10^{-01}$	U

Notes:

1. Source: Reference 2, Table 66.
2. LGV is light goods vehicle ≤ 3.5 t GVM.
3. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
4. Emissions are presented in units of kg TEQ/m³. Emission factor was derived from total hydrocarbon emission factor presented in Reference 2, Table 66, and organic speciation profile for diesel exhaust sourced from Reference 22.
5. Total VOC emission factor derived from total hydrocarbon emission factor presented in Reference 2, Table 66 and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 16: Emission factors (kg/km) for road transport vehicles - petrol LGVs

Substance	Emission factor[1,2] (kg/km)	Emission factor scientific notation (kg/km)	Rating
Benzene[3]	0.000012	1.22×10^{-05}	D
1,3 Butadiene (vinyl ethylene) [3]	0.000008	7.96×10^{-06}	D
Carbon monoxide	0.012	1.18×10^{-02}	B
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.0015	1.50×10^{-03}	B
Particulate matter 2.5 µm[4]	0.0000091	9.11×10^{-06}	U
Particulate matter 10.0 µm[3]	0.0000098	9.82×10^{-06}	D
Polycyclic aromatic hydrocarbons[5]	0.0000000025	2.48×10^{-09}	U
Sulfur dioxide[3]	0.000011	1.14×10^{-05}	D
Total volatile organic compounds	0.0012	1.16×10^{-03}	B

Notes:

1. Source: Reference 6, 7, 8, and 14.
2. Converted to kg/km based on fuel consumption of 14.61 L/100km for LGVs (average from CVE (Reference 7) and NISE (Reference 6) studies).
3. Based on UK 2000 g/L data from Reference 8
4. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14)
5. Emission factor presented in units of kg TEQ/km. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 17: Emission factors (kg/m³) for road transport vehicles - petrol LGVs

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Benzene[2]	0.09	9.00×10^{-02}	D
1,3 Butadiene (vinyl ethylene) [2]	0.059	5.90×10^{-02}	D
Carbon monoxide	87	$8.68 \times 10^{+01}$	B
Fluoride compounds[5]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	11	$1.10 \times 10^{+01}$	B
Particulate matter 2.5 µm[3]	0.067	6.68×10^{-02}	U
Particulate matter 10.0 µm[2]	0.072	7.20×10^{-02}	D
Polycyclic aromatic hydrocarbons[4]	0.000018	1.76×10^{-05}	U
Sulfur dioxide[2]	0.084	8.40×10^{-02}	D
Total volatile organic compounds	8.5	$8.50 \times 10^{+00}$	B

Notes:

1. Source: Reference 8, and 14.
2. Based on UK 2000 g/L data from Reference 8.
3. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
4. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.
5. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 18: Emission factors (kg/km) for road transport vehicles – LPG LGVs[2,3]

Substance	Emission factor[1] (kg/km)	Emission factor scientific notation (kg/km)	Rating
Benzene[4]	0	$0.00x10^{+00}$	U
1,3 Butadiene (vinyl ethylene)[4]	0	$0.00x10^{+00}$	U
Carbon monoxide	0.0062	$6.16x10^{-03}$	U
Fluoride compounds[4]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	0.0006	$6.00x10^{-04}$	U
Particulate matter 2.5 µm[4]	0	$0.00x10^{+00}$	U
Particulate matter 10.0 µm[4]	0	$0.00x10^{+00}$	U
Polycyclic aromatic hydrocarbons[5]	0.000000000021	$2.09x10^{-11}$	U
Sulfur dioxide[4]	0	$0.00x10^{+00}$	U
Total volatile organic compounds	0.00072	$7.22x10^{-04}$	U

Notes:

1. Source: Reference 7, Reference 9 Table 5.20, Reference 14, profile 120.
2. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors fro miscellaneous industrial vehicles.
3. Based on emissions for petrol and LPG passenger vehicles.
4. Emissions are negligible.
5. Emission factor presented in units of kg TEQ/km. Emission factor was derived from total VOC emission factor and organic speciation profile for LPG exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.

Table 19: Emission factors (kg/m³) for road transport vehicles – LPG LGVs[2,3]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Benzene[4]	0	$0.00x10^{+00}$	U
1,3 Butadiene (vinyl ethylene)[4]	0	$0.00x10^{+00}$	U
Carbon monoxide	35	$3.50x10^{+01}$	U
Fluoride compounds[4]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	3.4	$3.41x10^{+00}$	U
Particulate matter 2.5 µm[4]	0	$0.00x10^{+00}$	U
Particulate matter 10.0 µm[4]	0	$0.00x10^{+00}$	U
Polycyclic aromatic hydrocarbons[5]	0.0000041	$4.12x10^{-06}$	U
Sulfur dioxide[4]	0	$0.00x10^{+00}$	U
Total volatile organic compounds	4.1	$4.11x10^{+00}$	U

Notes:

1. Source: Reference 7, Reference 9 Table 5.20, Reference 14, profile 120.
2. When these vehicles are used on rough terrain, on steep grades or on poorly graded tracks, use the emission factors fro miscellaneous industrial vehicles.
3. Based on emissions for petrol and LPG passenger vehicles.
4. Emissions are negligible
5. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total VOC emission factor and organic speciation profile for LPG exhaust (assuming ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.

Table 20: Emission factors (kg/m³) for diesel vehicle exhaust emissions (MGV)[2]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	12	$1.21x10^{+01}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	17	$1.71x10^{+01}$	U
Particulate matter 2.5 µm	2.2	$2.25x10^{+00}$	U
Particulate matter 10.0 µm	2.3	$2.33x10^{+00}$	U
Polycyclic aromatic hydrocarbons[4]	0.00084	$8.36x10^{-04}$	U
Sulfur dioxide[3]	0.017	$1.67x10^{-02}$	U
Total volatile organic compounds[5]	2.1	$2.14x10^{+00}$	U

Notes:

1. Source: Reference 2, Table 66.
2. MGV is medium goods vehicle < 3.5 t GVM ≤ 12 t.
3. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
4. Emissions are presented in units of kg TEQ/m³. Emission factor was derived from total hydrocarbon emission factor presented in Reference 2, Table 66, and organic speciation profile for diesel exhaust sourced from Reference 22.
5. Total VOC emission factor derived from total hydrocarbon emission factor presented in Reference 2, Table 66 and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 21: Emission factors (kg/m³) for diesel vehicle exhaust emissions (HGV)[2]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	6.8	$6.81x10^{+00}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	23	$2.33x10^{+01}$	U
Particulate matter 2.5 µm	1.7	$1.73x10^{+00}$	U
Particulate matter 10.0 µm	1.8	$1.84x10^{+00}$	U
Polycyclic aromatic hydrocarbons[4]	0.00071	$7.10x10^{-04}$	U
Sulfur dioxide[3]	0.017	$1.67x10^{-02}$	U
Total volatile organic compounds[5]	1.8	$1.82x10^{+00}$	U

Notes:

1. Source: Reference 2, Table 66.
2. HGV is heavy goods vehicle <12 t GVM ≤ 25 t.
3. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
4. Emissions are presented in units of kg TEQ/m³. Emission factor was derived from total hydrocarbon emission factor presented in Reference 2, Table 66, and organic speciation profile for diesel exhaust sourced from Reference 22.
5. Total VOC emission factor derived from total hydrocarbon emission factor presented in Reference 2, Table 66 and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 22: Emission factors (kg/m³) for diesel vehicle exhaust emissions (very HGV)[2]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	8.5	$8.51 \times 10^{+00}$	U
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	22	$2.23 \times 10^{+01}$	U
Particulate matter 2.5 µm	1.1	$1.12 \times 10^{+00}$	U
Particulate matter 10.0 µm	1.2	$1.17 \times 10^{+00}$	U
Polycyclic aromatic hydrocarbons[4]	0.00040	3.97×10^{-04}	U
Sulfur dioxide[3]	0.017	1.67×10^{-02}	U
Total volatile organic compounds[5]	1.0	$1.02 \times 10^{+00}$	U

Notes:

1. Source: Reference 2, Table 66.
2. Very HGV is heavy goods vehicle >25 t GVM.
3. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
4. Emissions are presented in units of kg TEQ/m³. Emission factor was derived from total hydrocarbon emission factor presented in Reference 2, Table 66, and organic speciation profile for diesel exhaust sourced from Reference 22.
5. Total VOC emission factor derived from total hydrocarbon emission factor presented in Reference 2, Table 66 and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 23: Emission factors (kg/m³) for diesel commercial vehicle exhaust emissions (bus)[2]

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	9.1	$9.11 \times 10^{+00}$	U
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	30	$3.04 \times 10^{+01}$	U
Particulate matter 2.5 µm	2.1	$2.07 \times 10^{+00}$	U
Particulate matter 10.0 µm	2.1	$2.11 \times 10^{+00}$	U
Polycyclic aromatic hydrocarbons[4]	0.00046	4.61×10^{-04}	U
Sulfur dioxide[3]	0.017	1.67×10^{-02}	U
Total volatile organic compounds[5]	1.2	$1.18 \times 10^{+00}$	U

Notes:

1. Source: Reference 2, Table 66.
2. Bus is heavy bus >5 t GVM.
3. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
4. Emissions are presented in units of kg TEQ/m³. Emission factor was derived from total hydrocarbon emission factor presented in Reference 2, Table 66, and organic speciation profile for diesel exhaust sourced from Reference 22.
5. Total VOC emission factor derived from total hydrocarbon emission factor presented in Reference 2, Table 66 and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 24: Emission factors (kg/m³) for natural gas buses and trucks

Substance	Emission factor[1,2,3] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Carbon monoxide	1.73	$1.73x10^{+00}$	D
Fluoride compounds[9]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	6.85	$6.85x10^{+00}$	D
Particulate matter 2.5 µm[8]	0.0116	$1.16x10^{-02}$	U
Particulate matter 10.0 µm[6, 7]	0.0116	$1.19x10^{-02}$	D
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide[9]	0	$0.00x10^{+00}$	U
Total volatile organic compounds	ND	ND	NA

Notes:

1. Source: Reference 12.
2. Mumbai bus NMHC estimated assuming 9% NMHC of total exhaust hydrocarbons.
3. Fuel consumption is not reported but is calculated using the factor 1128 g(CO_2)/m³ for NG from Reference 12.
4. Calculations based on a NG liquid density of 410kg/m³.
5. Average fuel consumption of all studies was 90.54 L/100km.
6. Reported as PM from Reference 2, Table 77.
7. All PM emission factors can be used to estimate the PM_{10},, and $PM_{2.5}$ emissions (Reference 16).
8. The $PM_{2.5}/PM_{10}$ ratio is 1:1 for gaseous material combustion, (Reference 14, Profile 120).
9. Emissions are negligible.

Table 25: Emission factors (kg/m³) for LPG forklift emissions

Control	Substance	Emission factor[1,2] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Uncontrolled	Carbon monoxide	16	$1.60x10^{+01}$	E
Uncontrolled	Fluoride compounds	0	$0.00x10^{+00}$	U
Uncontrolled	Oxides of nitrogen	25	$2.53x10^{+01}$	E
Uncontrolled	Particulate matter 2.5 µm[3]	0	$0.00x10^{+00}$	U
Uncontrolled	Particulate matter 10.0 µm[3]	0	$0.00x10^{+00}$	U
Uncontrolled	Polycyclic aromatic hydrocarbons[5]	0.000000060	$5.98x10^{-08}$	U
Uncontrolled	Sulfur dioxide[3]	0	$0.00x10^{+00}$	U
Uncontrolled	Total volatile organic compounds[4]	2.1	$2.10x10^{+00}$	U
Closed loop/OEM catalyst	Carbon monoxide	6.5	$6.46x10^{+00}$	E
Closed loop/OEM catalyst	Fluoride compounds	0	$0.00x10^{+00}$	U
Closed loop/OEM catalyst	Oxides of nitrogen	0.81	$8.07x10^{-01}$	E
Closed loop/OEM catalyst	Particulate matter 2.5 µm[3]	0	$0.00x10^{+00}$	U
Closed loop/OEM catalyst	Particulate matter 10.0 µm[3]	0	$0.00x10^{+00}$	U
Closed loop/OEM catalyst	Polycyclic aromatic hydrocarbons[5]	0.000000023	$2.28x10^{-08}$	U
Closed loop/OEM catalyst	Sulfur dioxide[3]	0	$0.00x10^{+00}$	U
Closed loop/OEM catalyst	Total volatile organic compounds[4]	0.8	$8.00x10^{-01}$	U
Closed loop with new calibration	Carbon monoxide	13	$1.28x10^{+01}$	E
Closed loop with new calibration	Fluoride compounds	0	$0.00x10^{+00}$	U
Closed loop with new calibration	Oxides of nitrogen	1.1	$1.13x10^{+00}$	E
Closed loop with new calibration	Particulate matter 2.5 µm[3]	0	$0.00x10^{+00}$	U
Closed loop with new calibration	Particulate matter 10.0 µm[3]	0	$0.00x10^{+00}$	U
Closed loop with new calibration	Polycyclic aromatic hydrocarbons[5]	0.000000014	$1.42x10^{-08}$	U
Closed loop with new calibration	Sulfur dioxide[3]	0	$0.00x10^{+00}$	U
Closed loop with new calibration	Total volatile organic compounds[4]	0.5	$5.00x10^{-01}$	U
Closed loop with larger catalyst	Carbon monoxide	8.9	$8.88x10^{+00}$	E
Closed loop with larger catalyst	Fluoride compounds	0	$0.00x10^{+00}$	U
Closed loop with larger catalyst	Oxides of nitrogen	0	$0.00x10^{+00}$	E
Closed loop with larger catalyst	Particulate matter 2.5 µm[3]	0	$0.00x10^{+00}$	U
Closed loop with larger catalyst	Particulate matter 10.0 µm[3]	0	$0.00x10^{+00}$	U
Closed loop with larger catalyst	Polycyclic aromatic hydrocarbons[5]	0.000000014	$1.42x10^{-08}$	U
Closed loop with larger catalyst	Sulfur dioxide[3]	0	$0.00x10^{+00}$	U
Closed loop with larger catalyst	Total volatile organic compounds[4]	0.5	$5.00x10^{-01}$	U

Notes:

1. Source: Reference 10.
2. Converted using the LHV of 25.7 MJ/m³, density of 518 kg/m³ and heat rate of 15,922 kJ/kWh.
3. Assumed to be the same as for road transport vehicles operating on LPG (i.e. negligible).
4. Emission factors are for total hydrocarbons. It is assumed all hydrocarbons released are volatile organic compounds.
5. Emission factor presented in units of kg TEQ/m³. Emission factor was derived from total VOC emission factor and organic speciation profile for LPG exhaust (assuming equivalent emissions for vehicle type ADR37-01 and driving speed of 30 km/h) sourced from Reference 22.

B.2 Industrial vehicles

Table 26: Emission factors (kg/kWh) for diesel industrial vehicle (track-type tractor) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0029	$2.88x10^{-03}$	E
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00023	$2.28x10^{-04}$	U
Oxides of nitrogen	0.01	$1.05x10^{-02}$	E
Particulate matter 2.5 µm[2]	0.00085	$8.54x10^{-04}$	U
Particulate matter 10.0 µm	0.00093	$9.28x10^{-04}$	E
Polycyclic aromatic hydrocarbons[5]	0.00000039	$3.9x10^{-07}$	U
Sulfur dioxide[4]	0.0000073	$7.26x10^{-06}$	U
Total volatile organic compounds	0.001	$1.01x10^{-03}$	E

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.3 for Track-type tractor.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000027 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 27: Emission factors (kg/kWh) for diesel industrial vehicle (wheeled tractor) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0098	$9.84x10^{-03}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00038	$3.78x10^{-04}$	U
Oxides of nitrogen	0.016	$1.60x10^{-02}$	U
Particulate matter 2.5 µm[2]	0.0016	$1.56x10^{-03}$	U
Particulate matter 10.0 µm	0.0017	$1.70x10^{-03}$	U
Polycyclic aromatic hydrocarbons[5]	0.00000094	$9.4x10^{-07}$	U
Sulfur dioxide[4]	0.0000073	$7.26x10^{-06}$	U
Total volatile organic compounds	0.0024	$2.36x10^{-03}$	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.3 for wheeled tractor.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000027 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 28: Emission factors (kg/kWh) for diesel industrial vehicle (wheeled dozer) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0047	$4.70x10^{-03}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00022	$2.15x10^{-04}$	U
Oxides of nitrogen	0.011	$1.09x10^{-02}$	U
Particulate matter 2.5 µm[2]	0.00051	$5.07x10^{-04}$	U
Particulate matter 10.0 µm	0.00055	$5.51x10^{-04}$	U
Polycyclic aromatic hydrocarbons[5]	0.00000019	$1.9x10^{-07}$	U
Sulfur dioxide[4]	0.0000075	$7.49x10^{-06}$	U
Total volatile organic compounds	0.0005	$5.00x10^{-04}$	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.2 for wheeled dozer.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000028 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 29: Emission factors (kg/kWh) for diesel industrial vehicle (scraper) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0033	$3.28x10^{-03}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00038	$3.75x10^{-04}$	U
Oxides of nitrogen	0.01	$1.00x10^{-02}$	U
Particulate matter 2.5 µm[2]	0.00098	$9.75x10^{-04}$	U
Particulate matter 10.0 µm	0.0011	$1.06x10^{-03}$	U
Polycyclic aromatic hydrocarbons[5]	0.00000029	$2.9x10^{-07}$	U
Sulfur dioxide[4]	0.0000077	$7.73x10^{-06}$	U
Total volatile organic compounds	0.00074	$7.40x10^{-04}$	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.1 for scraper.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000028 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 30: Emission factors (kg/kWh) for diesel industrial vehicle (motor grader) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0021	2.06×10^{-03}	U
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00016	1.62×10^{-04}	U
Oxides of nitrogen	0.0096	9.57×10^{-03}	U
Particulate matter 2.5 µm[2]	0.00077	7.71×10^{-04}	U
Particulate matter 10.0 µm	0.00084	8.38×10^{-04}	U
Polycyclic aromatic hydrocarbons[5]	0.00000019	1.9×10^{-07}	U
Sulfur dioxide[4]	0.0000075	7.49×10^{-06}	U
Total volatile organic compounds	0.00048	4.80×10^{-04}	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.2 for motor grader.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000028 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 31: Emission factors (kg/kWh) for diesel industrial vehicle (wheeled loader) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0036	3.63×10^{-03}	D
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00026	2.64×10^{-04}	U
Oxides of nitrogen	0.012	1.18×10^{-02}	D
Particulate matter 2.5 µm[2]	0.00099	9.94×10^{-04}	U
Particulate matter 10.0 µm	0.0011	1.08×10^{-03}	D
Polycyclic aromatic hydrocarbons[5]	0.00000062	6.2×10^{-07}	U
Sulfur dioxide[4]	0.0000075	7.49×10^{-06}	U
Total volatile organic compounds	0.0016	1.59×10^{-03}	D

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.3 for wheeled loader.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000027 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 32: Emission factors (kg/kWh) for diesel industrial vehicle (track type loader) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.003	3.03×10^{-03}	U
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00013	1.34×10^{-04}	U
Oxides of nitrogen	0.012	1.25×10^{-02}	U
Particulate matter 2.5 µm[2]	0.00081	8.08×10^{-04}	U
Particulate matter 10.0 µm	0.00088	8.78×10^{-04}	U
Polycyclic aromatic hydrocarbons[5]	0.00000058	5.8×10^{-07}	U
Sulfur dioxide	0.0000075	7.49×10^{-06}	U
Total volatile organic compounds	0.0015	1.49×10^{-03}	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.3 for track-type loader.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000027 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 33: Emission factors (kg/kWh) for diesel industrial vehicle (off-highway truck) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0047	4.70×10^{-03}	U
Fluoride compounds[6]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.0003	2.95×10^{-04}	U
Oxides of nitrogen	0.011	1.09×10^{-02}	U
Particulate matter 2.5 µm[2]	0.00062	6.19×10^{-04}	U
Particulate matter 10.0 µm	0.00067	6.73×10^{-04}	U
Polycyclic aromatic hydrocarbons[5]	0.00000019	1.9×10^{-07}	U
Sulfur dioxide	0.0000077	7.73×10^{-06}	U
Total volatile organic compounds	0.0005	5.00×10^{-04}	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.1 for off-highway truck.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000028 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 34: Emission factors (kg/kWh) for diesel industrial vehicle (roller) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0081	$8.08x10^{-03}$	U
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00026	$2.63x10^{-04}$	U
Oxides of nitrogen	0.018	$1.75x10^{-02}$	U
Particulate matter 2.5 µm[2]	0.00096	$9.57x10^{-04}$	U
Particulate matter 10.0 µm	0.001	$1.04x10^{-03}$	U
Polycyclic aromatic hydrocarbons[5]	0.00000051	$5.1x10^{-07}$	U
Sulfur dioxide[4]	0.0000085	$8.55x10^{-06}$	U
Total volatile organic compounds	0.0013	$1.30x10^{-03}$	U

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 2.8 for roller.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000031 \text{ x } C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 35: Emission factors (kg/kWh) for diesel industrial vehicle (miscellaneous) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0062	$6.16x10^{-03}$	E
Fluoride compounds[6]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00027	$2.72x10^{-04}$	U
Oxides of nitrogen	0.015	$1.48x10^{-02}$	E
Particulate matter 2.5 µm[2]	0.0011	$1.11x10^{-03}$	U
Particulate matter 10.0 µm	0.0012	$1.21x10^{-03}$	E
Polycyclic aromatic hydrocarbons[5]	0.00000055	$5.5x10^{-07}$	U
Sulfur dioxide[4]	0.0000080	$7.98x10^{-06}$	U
Total volatile organic compounds	0.0014	$1.35x10^{-03}$	E

Notes:

1. Source: Reference 5. Table II-7.1, Reference 14.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 425 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 3.0 for miscellaneous.
4. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
5. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for diesel exhaust sourced from Reference 22.
6. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000029 \text{ x } C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 36: Emission factors (kg/kWh) for petrol industrial vehicle (wheeled tractor) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.19	$1.90x10^{-01}$	U
Fluoride compounds[7]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00034	$3.41x10^{-04}$	U
Oxides of nitrogen	0.0085	$8.54x10^{-03}$	U
Particulate matter 2.5 µm[2]	0.00045	$4.49x10^{-04}$	U
Particulate matter 10.0 µm	0.00048	$4.84x10^{-04}$	U
Polycyclic aromatic hydrocarbons[6]	0.0000000036	$3.6x10^{-09}$	U
Sulfur dioxide[5]	0.00018	$1.80x10^{-04}$	U
Total volatile organic compounds	0.0072	$7.16x10^{-03}$	U
TVOCs (Evaporative)[4]	0.031	$3.09x10^{-02}$	U
TVOCs (Crankcase)[4]	0.033	$3.26x10^{-02}$	U

Notes:

1. Source: Reference 5, Table II-7.2.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 2.0 for wheeled tractor.
4. The evaporative and crankcase emission factors are reported in kg/h of the vehicle used.
5. Sulfur dioxide emission factor was estimated based on a 150 ppm maximum sulfur content in petrol fuel as per the Australian Petrol Fuel Standard.
6. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust sourced from Reference 22.
7. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000044 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 37: Emission factors (kg/kWh) for petrol industrial vehicle (motor grader) exhaust emissions

Substance	**Emission factor[1,3] (kg/kWh)**	**Emission factor scientific notation (kg/kWh)**	**Rating**
Carbon monoxide	0.25	2.51×10^{-01}	U
Fluoride compounds[7]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00039	3.86×10^{-04}	U
Oxides of nitrogen	0.0066	6.57×10^{-03}	U
Particulate matter 2.5 µm[2]	0.00041	4.08×10^{-04}	U
Particulate matter 10.0 µm	0.00044	4.40×10^{-04}	U
Polycyclic aromatic hydrocarbons[6]	0.0000000042	4.2×10^{-09}	U
Sulfur dioxide[5]	0.00019	1.89×10^{-04}	U
Total volatile organic compounds	0.0085	8.48×10^{-03}	U
TVOCs (Evaporative)[4]	0.03	3.00×10^{-02}	U
TVOCs (Crankcase)[4]	0.037	3.71×10^{-02}	U

Notes:

1. Source: Reference 5, Table II-7.2.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 1.9 for motor grader.
4. The evaporative and crankcase emission factors are reported in kg/h of the vehicle used.
5. Sulfur dioxide emission factor was estimated based on a 150 ppm maximum sulfur content in petrol fuel as per the Australian Petrol Fuel Standard.
6. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust sourced from Reference 22.
7. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000046 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 38: Emission factors (kg/kWh) for petrol industrial vehicle (wheeled loader) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.22	2.19×10^{-01}	U
Fluoride compounds[7]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.0003	2.98×10^{-04}	U
Oxides of nitrogen	0.0073	7.27×10^{-03}	U
Particulate matter 2.5 µm[2]	0.00039	3.91×10^{-04}	U
Particulate matter 10.0 µm	0.00042	4.21×10^{-04}	U
Polycyclic aromatic hydrocarbons[6]	0.0000000037	3.7×10^{-09}	U
Sulfur dioxide[5]	0.00018	1.80×10^{-04}	U
Total volatile organic compounds	0.0075	7.46×10^{-03}	U
TVOCs (Evaporative)[4]	0.03	2.97×10^{-02}	U
TVOCs (Crankcase)[4]	0.048	4.82×10^{-02}	U

Notes:

1. Source: Reference 5, Table II-7.2.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 2.0 for wheeled loader.
4. The evaporative and crankcase emission factors are reported in kg/h of the vehicle used.
5. Sulfur dioxide emission factor was estimated based on a 150 ppm maximum sulfur content in petrol fuel as per the Australian Petrol Fuel Standard.
6. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust sourced from Reference 22.
7. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000044 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 39: Emission factors (kg/kWh) for petrol industrial vehicle (roller) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.27	2.71×10^{-01}	U
Fluoride compounds[7]	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.00034	3.43×10^{-04}	U
Oxides of nitrogen	0.0071	7.08×10^{-03}	U
Particulate matter 2.5 µm[2]	0.00049	4.89×10^{-04}	U
Particulate matter 10.0 µm	0.00053	5.27×10^{-04}	U
Polycyclic aromatic hydrocarbons[6]	0.0000000060	6.0×10^{-09}	U
Sulfur dioxide[5]	0.00021	2.11×10^{-04}	U
Total volatile organic compounds	0.012	1.24×10^{-02}	U
TVOCs (Evaporative)[4]	0.028	2.82×10^{-02}	U
TVOCs (Crankcase)[4]	0.055	5.55×10^{-02}	U

Notes:

1. Source: Reference 5, Table II-7.2.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 1.7 for roller.
4. The evaporative and crankcase emission factors are reported in kg/h of the vehicle used.
5. Sulfur dioxide emission factor was estimated based on a 150 ppm maximum sulfur content in petrol fuel as per the Australian Petrol Fuel Standard.
6. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust sourced from Reference 22.
7. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000052 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 40: Emission factors (kg/kWh) for petrol industrial vehicle (miscellaneous) exhaust emissions

Substance	Emission factor[1,3] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.27	$2.66x10^{-01}$	U
Fluoride compounds[7]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.0003	$2.98x10^{-04}$	U
Oxides of nitrogen	0.0065	$6.48x10^{-03}$	U
Particulate matter 2.5 µm[2]	0.00038	$3.77x10^{-04}$	U
Particulate matter 10.0 µm	0.00041	$4.06x10^{-04}$	U
Polycyclic aromatic hydrocarbons[6]	0.0000000043	$4.3x10^{-09}$	U
Sulfur dioxide[5]	0.00020	$2.20x10^{-04}$	U
Total volatile organic compounds	0.0087	$8.70x10^{-03}$	U
TVOCs (Evaporative)[4]	0.025	$2.54x10^{-02}$	U
TVOCs (Crankcase)[4]	0.051	$5.07x10^{-02}$	U

Notes:

1. Source: Reference 5, Table II-7.2.
2. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 400 from the California Emission Inventory and Reporting System, (Reference 14).
3. The emission factors can be converted from kg/kWh to kg/litre by multiplying the emission factors by 1.8 for miscellaneous vehicles.
4. The evaporative and crankcase emission factors are reported in kg/h of the vehicle used.
5. Sulfur dioxide emission factor was estimated based on a 150 ppm maximum sulfur content in petrol fuel as per the Australian Petrol Fuel Standard.
6. Emission factor presented in units of kg TEQ/kWh. Emission factor was derived from total VOC emission factor and organic speciation profile for petrol exhaust sourced from Reference 22.
7. It is expected that all fluoride present in petrol will be emitted as hydrogen fluoride. However, the fluoride content of petrol is unknown. If the fluoride content of petrol is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00000049 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in petrol fuel (ppm mass basis).

Table 41: Emission factors (kg/kg LPG) for miscellaneous LPG industrial vehicle exhaust emissions

Substance	Emission factor[1,2, 4,5,6] (kg/kg LPG)	Emission factor scientific notation (kg/kg LPG)	Rating
Carbon monoxide	0.3	$3.00x10^{-01}$	U
Fluoride compounds[7]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)[7]	0	$0.00x10^{+00}$	U
Oxides of nitrogen	0.015	$1.50x10^{-02}$	U
Particulate matter 2.5 µm[7]	0	$0.00x10^{+00}$	U
Particulate matter 10.0 µm[7]	0	$0.00x10^{+00}$	U
Polycyclic aromatic hydrocarbons[8]	0.0000000009	$9.40x10^{-10}$	U
Sulfur dioxide[7]	0	$0.00x10^{+00}$	U
Total volatile organic compounds	0.033	$3.27x10^{-02}$	U

Notes:

1. Source: Reference 5, Table II-7.1.
2. Based on emissions for petrol and LPG passenger cars. (Source: 9, Table 5.20)
3. Source: Reference 19.
4. Based on the average CO/CO_2 ratio from passenger vehicle CO emission tests, Reference: 20.
5. Assumes fuel consumption is the same as for petrol on a mass basis.
6. To convert the emission factors from kg/kg LPG to kg/kWh, multiply by 0.29 for industrial LPG vehicles.
7. Emissions are negligible.
8. Emission factor presented in units of kg TEQ/kg LPG. Emission factor was derived from total VOC emission factor and organic speciation profile for LPG exhaust sourced from Reference 22.

B.3 Stationary engines

Table 42: Emission factors (kg/kWh) for stationary large (greater than 450 kW) diesel engines

Substance	Emission factor[1,4] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0033	$3.34x10^{-03}$	C
Fluoride compounds	0	$0.00x10^{+00}$	U
Oxides of nitrogen – uncontrolled [5]	0.015	$1.46x10^{-02}$	B
Oxides of nitrogen – controlled [5]	0.0079	$7.90x10^{-03}$	B
Particulate matter 2.5 µm [3]	0.00042	$4.16x10^{-04}$	U
Particulate matter 10.0 µm	0.00043	$4.26x10^{-04}$	B
Polycyclic aromatic hydrocarbons[6]	0.00000000006	$6x10^{-11}$	U
Sulfur dioxide	$0.0049 \times S^2$	$4.92x10^{-03} \times S^2$	B
Total volatile organic compounds	0.00038	$3.84x10^{-04}$	C

Notes:

1. Source: Reference 1, Table 3.4-1, Reference 14.
2. S is the fuel sulfur content (wt%) in the diesel. It is multiplied by the coefficient given to obtain the SO_2 EF. For example if sulfur content is 1.5%, then S = 1.5. If the diesel fuel sulfur content is 50 ppm, S = 0.005%, if the diesel fuel sulfur content is 10 ppm, S = 0.001%.
3. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 116 from the California Emission Inventory and Reporting System, (Reference 14).
4. Heat rate varies and corresponds to approximately 9,115 kJ/kWh to 11,325 kJ/kWh, for energy content of 38.2 MJ/L, suggesting variations in average engine efficiencies for each substance of ± 10%.
5. Unless otherwise stated the engines are controlled. Controlled NO_x is ignition timing retard (Reference 1, Table 3.4-1).
6. Emission factor presented in units of kg TEQ/kWh. Derived based on data presented in Reference 1, Table 3.4-3 and the ratio between PAH emissions and VOC emissions (in units of kg/m^3).

Table 43: Emission factors (kg/m³) for stationary large (greater than 450 kW) diesel engines

Substance	Emission factor[4] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Acetaldehyde [6]	0.00041	$4.14x10^{-04}$	E
Benzene [6]	0.013	$1.28x10^{-02}$	E
Carbon monoxide [1]	14	$1.40x10^{+01}$	C
Fluoride compounds[8]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde) [6]	0.0013	$1.30x10^{-03}$	E
Oxides of nitrogen – uncontrolled [1, 5]	53	$5.26x10^{+01}$	B
Oxides of nitrogen – controlled [1, 5]	31	$3.12x10^{+01}$	B
Particulate matter 2.5 µm [1,3]	1.6	$1.60x10^{+00}$	U
Particulate matter 10.0 µm[1]	1.6	$1.64x10^{+00}$	B
Polycyclic aromatic hydrocarbons[6,7]	0.00000019	$1.90x10^{-07}$	U
Sulfur dioxide [1]	$17 \times S^2$	$1.66x10^{+01} \times S^2$	B
Toluene (methylbenzene) [6]	0.0046	$4.62x10^{-03}$	E
Total volatile organic compounds [1]	1.3	$1.32x10^{+00}$	C
Xylenes (individual or mixed isomers) [6]	0.0032	$3.22x10^{-03}$	E

Notes:

1. Source: Reference 1, Table 3.4-1, Reference 14.
2. S signifies the fuel sulfur content (wt%) in the diesel. It is multiplied by the coefficient given to obtain the SO_2 EF. For example if sulfur content is 1.5%, then S = 1.5. If the diesel fuel sulfur content is 50 ppm, S = 0.005%, if the diesel fuel sulfur content is 10 ppm, S = 0.001%.
3. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 116 from the California Emission Inventory and Reporting System, (Reference 14).
4. Heat rate varies and corresponds to approximately 9,115 kJ/kWh to 11,325 kJ/kWh, for energy content of 38.2 MJ/L, suggesting variations in average engine efficiencies for each substance of ± 10%.
5. Unless otherwise stated the engines are controlled. Controlled NO_x is ignition timing retard (Reference 1, Table 3.4-1).
6. Source: Reference 1, Table 3.4-3.
7. Emission factor presented in units of kg TEQ/m³.
8. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 44: Emission factors (kg/kWh) for stationary large (greater than 450 kW) dual fuel engines (fuel mixture of up to 25% waste oil and diesel)[5]

Substance	Emission factor[1,4] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0033	3.34×10^{-03}	C
Fluoride compounds	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen – uncontrolled [6]	0.015	1.46×10^{-02}	B
Oxides of nitrogen – controlled [6]	0.0079	7.90×10^{-03}	B
Particulate matter 2.5 µm [3]	0.00042	4.16×10^{-04}	U
Particulate matter 10.0 µm	0.00043	4.26×10^{-04}	B
Polycyclic aromatic hydrocarbons[7]	0.00000000006	6×10^{-11}	U
Sulfur dioxide	$0.0049 \times S^2$	$4.92 \times 10^{-03} \times S^2$	B
Total volatile organic compounds	0.00038	3.84×10^{-04}	C

Notes:

1. Source: Reference 1, Table 3.4-1, Reference 14, Emissions for dual fuel engines aligns with emissions from 100% diesel engines. (Reference 2, Section 5.1.1.2).
2. S is the fuel sulfur content (wt%) in the diesel. It is multiplied by the coefficient given to obtain the SO_2 EF. For example if sulfur content is 1.5%, then S = 1.5. If the diesel fuel sulfur content is 50 ppm, S = 0.005%, if the diesel fuel sulfur content is 10 ppm, S = 0.001%.
3. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 116 from the California Emission Inventory and Reporting System, (Reference 14)
4. Heat rate varies and corresponds to approximately 9,115 kJ/kWh to 11,325 kJ/kWh, for energy content of 38.2 MJ/L, suggesting variations in average engine efficiencies for each substance of ± 10%.
5. Dual fuel refers to a fuel mixture of up to 25% waste oil with diesel fuel.
6. Unless otherwise stated the engines are controlled. Controlled NO_x is ignition timing retard (Reference 1, Table 3.4-1)
7. Emission factor presented in units of kg TEQ/kWh. Derived based on data presented in Reference 1, Table 3.4-3 and the ratio between PAH emissions and VOC emissions (in units of kg/m³).

Table 45: Emission factors (kg/m³) for stationary large (greater than 450 kW) dual fuel engines (fuel mixture of up to 25% waste oil with diesel fuel)[5]

Substance	Emission factor[1,4] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Acetaldehyde	0.00041	$4.14x10^{-04}$	E
Benzene	0.013	$1.28x10^{-02}$	E
Carbon monoxide	14	$1.40x10^{+01}$	C
Fluoride compounds[8]	0.00088xF	$8.81x10^{-04}$xF	U
Formaldehyde (methyl aldehyde)	0.0013	$1.30x10^{-03}$	E
Oxides of nitrogen – uncontrolled [6]	53	$5.26x10^{+01}$	B
Oxides of nitrogen – controlled [6]	31	$3.12x10^{+01}$	B
Particulate matter 2.5 µm [3]	1.6	$1.60x10^{+00}$	U
Particulate matter 10.0 µm	1.6	$1.64x10^{+00}$	B
Polycyclic aromatic hydrocarbons[7]	0.00000019	$1.90x10^{-07}$	U
Sulfur dioxide	$17\times S^2$	$1.66x10^{+01}\times S^2$	B
Toluene (methylbenzene)	0.0046	$4.62x10^{-03}$	E
Total volatile organic compounds	1.3	$1.32x10^{+00}$	C
Xylenes (individual or mixed isomers)	0.0032	$3.22x10^{-03}$	E

Notes:

1. Source: Reference 1, Table 3.4-1, Reference 14. Emissions for dual fuel engines align with emissions from 100% diesel engines. (Reference 2, Section 5.1.1.2).
2. S signifies the fuel sulfur content (wt%) in the diesel. It is multiplied by the coefficient given to obtain the SO_2 EF. For example if sulfur content is 1.5%, then S = 1.5. If the diesel fuel sulfur content is 50 ppm, S = 0.005%, if the diesel fuel sulfur content is 10 ppm, S = 0.001%.
3. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 116 from the California Emission Inventory and Reporting System, (Reference 14).
4. Heat rate varies and corresponds to approximately 9,115 kJ/kWh to 11,325 kJ/kWh, for energy content of 38.2 MJ/L, suggesting variations in average engine efficiencies for each substance of ± 10%.
5. Dual fuel refers to a fuel mixture of up to 25% waste oil with diesel fuel.
6. Unless otherwise stated the engines are controlled. Controlled NO_x is ignition timing retard (Reference 1, Table 3.4-1).
7. Emission factor presented in units of kg TEQ/m³. Source: Reference 1, Table 3.4-3. Emissions for dual fuel engines align with emissions from 100% diesel engines. (Reference 2, Section 5.1.1.2).
8. F signifies the fuel fluoride content (ppm (mass basis)). If the fluoride content of fuel equals 5 ppm, then F = 5.

Table 46: Emission factors (kg/kWh) for dual fuel engines[2] (fuel mixture of up 95% natural gas[5,6] and 5% diesel)

Substance	Emission factor[1,4] (kg/kWh)	Emission factor scientific notation[4] (kg/kWh)	Rating
Carbon monoxide	0.0046	4.56×10^{-03}	D
Fluoride compounds[7]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.011	1.09×10^{-02}	D
Particulate matter 2.5 µm	ND[3]	ND[3]	NA[3]
Particulate matter 10.0 µm	ND[3]	ND[3]	NA[3]
Polycyclic aromatic hydrocarbons	ND[3]	ND[3]	NA[3]
Sulfur dioxide	$0.00025S_1 + 0.0058S_2$	$2.47 \times 10^{-04}S_1 + 5.82 \times 10^{-03}S_2$	B
Total volatile organic compounds	0.0008	8.03×10^{-04}	D

Notes:

1. Source: Reference 1, Table 3.4-1.
2. Dual fuel refers to 95% wt natural gas and 5% wt diesel.
3. ND-No data, NA – Not applicable.
4. 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.
5. Energy content of natural gas is 38.9MJ/Sm³.
6. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
7. Assumed to be negligible.

Table 47: Emission factors (kg/m³) for dual fuel engines (fuel mixture of up 95% natural gas and 5% diesel)[2,5,6]

Substance	Emission factor[1,4] (kg/m³)	Emission factor scientific notation[4] (kg/m³)	Rating
Carbon monoxide	0.020	2.03×10^{-02}	D
Fluoride compounds[7]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.047	4.72×10^{-02}	D
Particulate matter 2.5 µm	ND[3]	ND[3]	NA[3]
Particulate matter 10.0 µm	ND[3]	ND[3]	NA[3]
Polycyclic aromatic hydrocarbons	ND[3]	ND[3]	NA[3]
Sulfur dioxide	$0.00087S_1 + 0.015S_2$	$8.74 \times 10^{-04}S_1 + 1.56 \times 10^{-02}S_2$	B
Total volatile organic compounds	0.0035	3.49×10^{-03}	D

Notes:

1. Source: Reference 1, Table 3.4-1.
2. Dual fuel refers to 95% wt natural gas and 5% wt diesel.
3. ND-No data, NA – not applicable.
4. 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.
5. Energy content of natural gas is 38.9 MJ/Sm³.
6. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
7. Assumed to be negligible.

Table 48: Emission factors (kg/m³) for uncontrolled dual fuel (NG/diesel) engines (fuel mixture of 90% natural gas and 10% diesel)[2]

Substance	Emission factor[1,3] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Benzene	0.047	4.70×10^{-02}	U
Carbon monoxide	34	$3.42 \times 10^{+01}$	U
Ethylbenzene	0.0012	1.21×10^{-03}	U
Fluoride compounds[7]	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	18	$1.76 \times 10^{+01}$	U
Particulate matter 2.5 µm	ND	ND	NA
Particulate matter 10.0 µm	ND	ND	NA
Polycyclic aromatic hydrocarbons	0.084	8.40×10^{-02}	U
Sulfur dioxide[6]	0.0017	1.67×10^{-03}	U
Toluene (methylbenzene)	0.015	1.54×10^{-02}	U
Total volatile organic compounds[4]	10	$1.05 \times 10^{+01}$	U
Xylenes (individual or mixed isomers)[5]	0.0021	2.11×10^{-03}	U

Notes:

1. Source: Reference 2, Table 34.
2. Dual fuel refers to 90% wt natural gas and 10% wt diesel.
3. Calculated from measured emission data averaged from two tests for one large engine (approx 2,000 kW) firing 10% diesel/90% Natural gas.
4. Using measured data for non-methane VOC.
5. Using measured data for 1,3-Xylene.
6. Sulfur dioxide emission factor was estimated based on 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard and negligible sulfur in natural gas.
7. Assumed to be negligible.

Table 49: Emission factors (kg/kWh) for stationary small (less than 450 kW) diesel engines

Substance	Emission factor[1,2] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0041	$4.06x10^{-03}$	D
Fluoride compounds	0	$0.00x10^{+00}$	U
Oxides of nitrogen	0.019	$1.88x10^{-02}$	D
Particulate matter 2.5 µm[3]	0.0013	$1.31x10^{-03}$	U
Particulate matter 10.0 µm	0.0013	$1.34x10^{-03}$	D
Polycyclic aromatic hydrocarbons[7]	0.00000000006	$6x10^{-11}$	U
Sulfur dioxide[6]	0.0000043	$4.28x10^{-06}$	U
Total volatile organic compounds[4]	0.0014	$1.37x10^{-03}$	E
TVOCs (Crankcase)[4]	0.000024	$2.40x10^{-05}$	E
TVOCs (Evaporative)	negligible	negligible	E
TVOCs (Exhaust) [4]	0.0013	$1.34x10^{-03}$	D
TVOCs (Refuelling)	negligible	negligible	E

Notes:

1. Source: Reference 3, Table 3.3-1, Reference 14.
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. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 116 from the California Emission Inventory and Reporting System, (Reference 14).
4. In the source data the organic compounds are provided as Total Organic Compounds (TOC). To convert TOC to VOC the following relationship was used to determine the TVOCs: TVOCs = TOC/1.1167.
5. To determine the EF based on volume of fuel used. For diesel the value of 38.21 MJ/L was used to obtain this value (Reference 15, page 51).
6. Sulfur dioxide emission factor was estimated based on a 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard and emission factor ratios presented in Reference 3, Table 3.3-1, Reference 14 to convert from kg/m³ to kg/kWh.
7. Emission factor presented in units of kg TEQ/kWh. Derived based on data presented in Reference 3, Table 3.3-1 and the ratio between PAH emissions and VOC emissions (in units of kg/m³).

Table 50: Emission factors (kg/m³) for stationary small (less than 450 kW) diesel engines

Substance	Emission factor[2] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Acetaldehyde[6]	0.013	$1.26x10^{-02}$	E
Benzene[6]	0.015	$1.53x10^{-02}$	E
1,3 Butadiene (vinyl ethylene)[6]	0.00064	$6.43x10^{-04}$	E
Carbon monoxide [1]	16	$1.56x10^{+01}$	D
Fluoride compounds[9]	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)[6]	0.019	$1.94x10^{-02}$	E
Oxides of nitrogen [1]	72	$7.25x10^{+01}$	D
Particulate matter 2.5 µm [1,3]	5	$4.98x10^{+00}$	U
Particulate matter 10.0 µm[1]	5.1	$5.10x10^{+00}$	D
Polycyclic aromatic hydrocarbons[8]	0.00000024	$2.42x10^{-07}$	U
Sulfur dioxide[7]	0.017	$1.67x10^{-02}$	U
Toluene (methylbenzene)[6]	0.0067	$6.72x10^{-03}$	D
Total volatile organic compounds[1,4]	5.3	$5.30x10^{+00}$	E
TVOCs (Crankcase)[1,4]	0.15	$1.47x10^{-01}$	E
TVOCs (Evaporative)[1,4]	negligible	negligible	E
TVOCs (Exhaust)[1,4]	5.2	$5.15x10^{+00}$	D
TVOCs (Refuelling)[1,4]	negligible	negligible	E
Xylenes (individual or mixed isomers)[6]	0.0047	$4.69x10^{-03}$	U

Notes:

1. Source: Reference 3, Table 3.3-1, Reference 14.
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. Emission factor for $PM_{2.5}$ is calculated using PM profile ID 116 from the California Emission Inventory and Reporting System, (Reference 14).
4. In the source data the organic compounds are provided as Total Organic Compounds (TOC). To convert TOC to VOC the following relationship was used to determine the TVOCs: TVOCs = TOC/1.1167.
5. To determine the EF based on volume of fuel used. For diesel the value of 38.21 MJ/L was used to obtain this value (Reference 15, page 51).
6. Source: Reference 3, Table 3.3-2.
7. Sulfur dioxide emission factor was estimated based on 10 ppm maximum sulfur content in diesel fuel as per the Australian Diesel Fuel Standard.
8. Emission factor presented in units of kg TEQ/m³. Source: Reference 3, Table 3.3-2.
9. It is expected that all fluoride present in diesel will be emitted as hydrogen fluoride. However, the fluoride content of diesel is unknown. If the fluoride content of diesel is known the emission factor can be calculated using the following equation: $EF_{fluoride} = 0.00088 \times C_{fluoride}$, where $C_{fluoride}$ is the concentration of fluoride in diesel fuel (ppm mass basis).

Table 51: Emission factors (kg/kWh) for uncontrolled gas turbines natural gas engines

Substance	Emission factor (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
1,3-Butadiene	0.00000000067	$6.65x10^{-10}$	U
Acetaldehyde	0.000000062	$6.19x10^{-08}$	U
Acrolein	0.0000000099	$9.91x10^{-09}$	U
Benzene	0.000000019	$1.86x10^{-08}$	U
Carbon monoxide	0.00013	$1.27x10^{-04}$	U
Ethylbenzene	0.000000050	$4.95x10^{-08}$	U
Fluoride compounds	0	$0.00x10^{+00}$	U
Formaldehyde	0.0000011	$1.10x10^{-06}$	U
Oxides of nitrogen	0.00050	$4.95x10^{-04}$	U
Particulate matter 2.5 µm	0.0000029	$2.94x10^{-06}$	U
Particulate matter 10.0 µm	0.0000029	$2.94x10^{-06}$	U
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide[4]	0.00000079	$7.86x10^{-07}$	U
Toluene (methylbenzene)	0.00000020	$2.01x10^{-07}$	U
Total volatile organic compounds[2]	0.0000033	$3.25x10^{-06}$	U
Xylenes (individual or mixed isomers)	0.00000010	$9.91x10^{-08}$	U

Notes:

1. Source: Reference 23, Table 3.1-1, Table 3.1-2a, Table 3.1-3.
2. Energy content of natural gas is 38.9 MJ/Sm³.
3. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
4. SO_2 emission factor is estimated based on a sulfur content of 4 mg/m³ in natural gas.

Table 52: Emission factors (kg/m³) for uncontrolled gas turbines natural gas engines

Substance	Emission factor [5] (kg/m³)	Emission factor scientific notation [5] (kg/m³)	Rating
1,3-Butadiene	0.000000011	$1.09x10^{-08}$	U
Acetaldehyde	0.0000010	$1.01x10^{-06}$	U
Acrolein	0.00000016	$1.62x10^{-07}$	U
Benzene	0.00000030	$3.03x10^{-07}$	U
Carbon monoxide	0.0021	$2.07x10^{-03}$	U
Ethylbenzene	0.00000081	$8.09x10^{-07}$	U
Fluoride compounds	0	$0.00x10^{+00}$	U
Formaldehyde	0.000018	$1.80x10^{-05}$	U
Oxides of nitrogen	0.0081	$8.09x10^{-03}$	U
Particulate matter 2.5 µm	0.000048	$4.80x10^{-05}$	U
Particulate matter 10.0 µm	0.000048	$4.80x10^{-05}$	U
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide[4]	0.000013	$1.28x10^{-05}$	U
Toluene (methylbenzene)	0.0000033	$3.29x10^{-06}$	U
Total volatile organic compounds[2]	0.000053	$5.31x10^{-05}$	U
Xylenes (individual or mixed isomers)	0.0000016	$1.62x10^{-06}$	U

Notes:

1. Source: Reference 23, Table 3.1-1, Table 3.1-2a, Table 3.1-3
2. Energy content of natural gas is 38.9 MJ/Sm³.
3. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
4. SO_2 emission factor is estimated based on a sulfur content of 4 mg/m³ in natural gas.

Table 53: Emission factors (kg/m³) for uncontrolled 2-stroke lean burn natural gas engines

Substance	Emission factor (kg/m³)	Emission factor scientific notation (kg/m³)	Rating[2]
Acetaldehyde	0.00013	$1.30x10^{-04}$	A
Acrolein	0.00013	$1.30x10^{-04}$	A
Benzene	0.0000325	$3.25x10^{-05}$	A
1,3 Butadiene (vinyl ethylene)	0.0000137	$1.37x10^{-05}$	D
Chloroform (trichloromethane)	0.000000788	$7.88x10^{-07}$	C
Carbon monoxide [6]	0.00591	$5.91x10^{-03}$	A
Carbon monoxide [7]	0.00646	$6.46x10^{-03}$	A
Dichloroethane	0.000000706	$7.06x10^{-07}$	D
Ethylbenzene	0.00000181	$1.81x10^{-06}$	B
Fluoride compounds	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.000924	$9.24x10^{-04}$	A
n-Hexane	0.00000745	$7.45x10^{-06}$	C
Methanol	0.0000415	$4.15x10^{-05}$	A
Oxides of nitrogen [6]	0.0325	$3.25x10^{-02}$	A
Oxides of nitrogen [7]	0.0531	$5.31x10^{-02}$	A
Phenol	0.000000705	$7.05x10^{-07}$	C
Particulate matter 2.5 µm[5]	0.000643	$6.43x10^{-04}$	U
Particulate matter 10.0 µm	0.000643	$6.43x10^{-04}$	C
Polycyclic aromatic hydrocarbons[8]	0.0000000009	$9.1x10^{-10}$	E
Sulfur dioxide[9]	0.000013	$1.28x10^{-05}$	U
Styrene (ethenylbenzene)	0.000000917	$9.17x10^{-07}$	A
Toluene (methylbenzene)	0.0000161	$1.61x10^{-05}$	A
Vinyl chloride monomer	0.000000413	$4.13x10^{-07}$	C
Total volatile organic compounds[3]	0.00201	$2.01x10^{-03}$	C
Xylenes (individual or mixed isomers)	0.00000449	$4.49x10^{-06}$	A

Notes:

1. Source: Reference 18, Table 3.2-1.
2. Relates to the certainty of using the EF to determine substance levels.
3. Energy content of natural gas is 38.9 MJ/Sm³.
4. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
5. The $PM_{2.5}/PM_{10}$ ratio is 1:1 for gaseous material combustion, (Reference 14, Profile 120).
6. Carbon monoxide and oxides of nitrogen, when the load is <90%.
7. Carbon monoxide and oxides of nitrogen, when 90%< Load < 105%.
8. Emission factor presented in units of kg TEQ/m³.
9. SO_2 emission factor is estimated based on a sulfur content of 4 mg/m³ in natural gas.

Table 54: Emission factors (kg/m³) for uncontrolled 4-stroke natural gas engines

Substance	Emission factor (kg/m³)	Emission factor scientific notation (kg/m³)	Rating[2]
Acetaldehyde	0.00014	$1.40x10^{-04}$	A
Benzene	0.00000737	$7.37x10^{-06}$	A
Biphenyl (1,1-biphenyl)	0.00000355	$3.55x10^{-06}$	D
1,3 Butadiene (vinyl ethylene)	0.00000447	$4.47x10^{-06}$	D
Chloroethane (ethyl chloride)	0.0000000313	$3.13x10^{-08}$	D
Chloroform (trichloromethane)	0.000000477	$4.77x10^{-07}$	E
Carbon monoxide [6]	0.00932	$9.32x10^{-03}$	B
Carbon monoxide [7]	0.00531	$5.31x10^{-03}$	C
Dichloroethane	0.000000045	$4.5x10^{-07}$	E
Ethylbenzene	0.000000665	$6.65x10^{-07}$	B
Fluoride compounds	0	$0.00x10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.000884	$8.84x10^{-04}$	A
n-Hexane	0.0000186	$1.86x10^{-05}$	C
Methanol	0.0000419	$4.19x10^{-05}$	B
Oxides of nitrogen [6]	0.0142	$1.42x10^{-02}$	B
Oxides of nitrogen [7]	0.0683	$6.83x10^{-02}$	B
Phenol	0.000000402	$4.02x10^{-07}$	C
Particulate matter 2.5 µm[5]	0.00000129	$1.29x10^{-06}$	U
Particulate matter 10.0 µm	0.00000129	$1.29x10^{-06}$	D
Polycyclic aromatic hydrocarbons[8]	0.0000000029	$2.89x10^{-09}$	U
Sulfur dioxide[9]	0.000013	$1.28x10^{-05}$	A
Styrene (ethenylbenzene)	0.000000395	$3.95x10^{-07}$	E
Toluene (methylbenzene)	0.00000683	$6.83x10^{-06}$	B
Vinyl chloride monomer	0.000000249	$2.49x10^{-07}$	C
Total volatile organic compounds	0.00198	$1.98x10^{-03}$	C
Xylenes (individual or mixed isomers)	0.00000308	$3.08x10^{-06}$	B

Notes:

1. Source: Reference 18, Table 3.2-2.
2. Relates to the certainty of using the EF to determine substance levels.
3. Energy content of Natural gas is 38.9 MJ/Sm³.
4. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
5. The $PM_{2.5}/PM_{10}$ ratio is 1:1 for gaseous material combustion, (Reference 14, Profile 120).
6. Carbon monoxide and oxides of nitrogen, when the load is <90%.
7. Carbon monoxide and oxides of nitrogen, when 90%< Load < 105%.
8. Emission factor presented in units of kg TEQ/m³.
9. SO_2 emission factor is estimated based on a sulfur content of 4 mg/m³ in natural gas.

Table 55: Emission factors (kg/Nm³ fuel) for uncontrolled 4-stroke reciprocating stationary engines (biogas)

Substance	Emission factor[1] (kg/Nm³ fuel)	Emission factor scientific notation (kg/Nm³ fuel)	Rating
Carbon monoxide	0.016	$1.59x10^{-02}$	E
Fluoride compounds	0	$0.00x10^{+00}$	U
Oxides of nitrogen	0.0074	$7.35x10^{-03}$	E
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide	0.0031	$3.06x10^{-03}$	E

Notes:

1. Source: Reference 2, Table 80.
2. Methane content approximately 70%.
3. Methane energy content approximately 35.9 MJ/Nm³.

Table 56: Emission factors (kg/kWh) for uncontrolled 4-stroke reciprocating stationary engines (biogas)

Substance	Emission factor[1] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Carbon monoxide	0.0067	6.68×10^{-03}	E
Fluoride compounds	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.0031	3.09×10^{-03}	E
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide	0.0013	1.29×10^{-03}	E

Notes:
1. Source: Reference 2, Table 80.
2. Methane content approximately 70%.
3. Methane energy content approximately 35.9 MJ/Nm³.
4. Converted using a heat rate of 10,000 kJ/kWh.

Table 57: Emission factors (kg/m³) for uncontrolled 4-stoke rich burn natural gas engines

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating[2]
Acetaldehyde	0.0000467	4.67×10^{-05}	C
Benzene	0.0000264	2.64×10^{-05}	B
1,3 Butadiene (vinyl ethylene)	0.0000111	1.11×10^{-05}	D
Chloroform (trichloromethane)	0.000000229	2.29×10^{-07}	E
Carbon monoxide [6]	0.0588	5.88×10^{-02}	C
Carbon monoxide [7]	0.0623	6.23×10^{-02}	A
Dichloroethane	0.000000189	1.89×10^{-07}	E
Ethylbenzene	0.000000415	4.15×10^{-07}	E
Fluoride compounds	0	$0.00 \times 10^{+00}$	U
Formaldehyde (methyl aldehyde)	0.000343	3.43×10^{-04}	A
Methanol	0.0000512	5.12×10^{-05}	D
Oxides of nitrogen [6]	0.038	3.80×10^{-02}	C
Oxides of nitrogen [7]	0.037	3.70×10^{-02}	A
Particulate matter 2.5 µm[5]	0.000159	1.59×10^{-04}	U
Particulate matter 10.0 µm	0.000159	1.59×10^{-04}	E
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide[8]	0.000013	1.28×10^{-05}	U
Styrene (ethenylbenzene)	0.000000199	1.99×10^{-07}	E
Toluene (methylbenzene)	0.00000934	9.34×10^{-06}	A
Vinyl chloride monomer	0.00000012	1.20×10^{-07}	E
Total volatile organic compounds	0.000496	4.96×10^{-04}	C
Xylenes (individual or mixed isomers)	0.00000326	3.26×10^{-06}	A

Notes:
1. Source: Reference 18, Table 3.2-3.
2. Relates to the certainty of using the EF to determine substance levels.
3. Energy content of Natural gas is 38.9 MJ/Sm³.
4. m³ of natural gas refers to Sm³ @ 1 atm pressure and 15°C.
5. The $PM_{2.5}/PM_{10}$ ratio is 1:1 for gaseous material combustion, (Reference 14, Profile 120).
6. Carbon monoxide and oxides of nitrogen, when the load is <90%.
7. Carbon monoxide and oxides of nitrogen, when 90%< Load < 105%.
8. SO_2 emission factor is estimated based on a sulfur content of 4 mg/m³ in natural gas.

Table 58: Emission factors (kg/m³) for uncontrolled landfill gas fired turbines

Substance	Emission factor[1] (kg/m³)	Emission factor scientific notation (kg/m³)	Rating
Acetonitrile	0.0000001	1.00×10^{-07}	U
Benzene	0.00000018	1.76×10^{-07}	U
Carbon monoxide	0.0037	3.68×10^{-03}	U
Chloroform (trichloromethane)	0.000000012	1.17×10^{-08}	U
Dichloromethane	0.000000019	1.92×10^{-08}	U
Fluoride compounds	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.0012	1.17×10^{-03}	U
Particulate matter 10.0 µm	0.00019	1.92×10^{-04}	U
Particulate matter 2.5 µm	0.00019	1.92×10^{-04}	U
Polycyclic aromatic hydrocarbons	ND	ND	NA
Sulfur dioxide	0.00038	3.76×10^{-04}	U
Tetrachloroethylene	0.000000021	2.09×10^{-08}	U
Toluene (methylbenzene)	0.00000092	9.20×10^{-07}	U
Total volatile organic compounds	0.00011	1.09×10^{-04}	U
Trichoroethylene	0.000000016	1.59×10^{-08}	U
Xylenes (individual or mixed isomers)	0.00000026	2.59×10^{-07}	U
Vinyl chloride monomer	0.000000013	1.34×10^{-08}	U

Notes:
1. Original US EPA42 data in lb/MMBTU. Source: Reference 23 and Table 79, Reference 2.
2. Landfill gas composition assumed as 50% CH_4, 27% CO_2, 23% N_2,; Average landfill gas heating value (HHV) of 19.45 MJ/Nm³.

Table 59: Emission factors (kg/kWh) for uncontrolled landfill gas fired turbines

Substance	Emission factor[1] (kg/kWh)	Emission factor scientific notation (kg/kWh)	Rating
Acetonitrile	0.000000051	5.11×10^{-08}	U
Benzene	0.000000089	8.93×10^{-08}	U
Carbon monoxide	0.0019	1.87×10^{-03}	U
Chloroform (trichloromethane)	0.000000006	5.96×10^{-09}	U
Dichloromethane	0.000000009	9.79×10^{-09}	U
Fluoride compounds	0	$0.00 \times 10^{+00}$	U
Oxides of nitrogen	0.0006	5.96×10^{-04}	U
Particulate matter 10.0 µm	0.000098	9.79×10^{-05}	U
Particulate matter 2.5 µm	0.000098	9.79×10^{-05}	U
Sulfur dioxide	0.00019	1.91×10^{-04}	U
Polycyclic aromatic hydrocarbons	ND	ND	NA
Tetrachloroethylene	0.000000011	1.06×10^{-08}	U
Toluene (methylbenzene)	0.00000047	4.68×10^{-07}	U
Total volatile organic compounds	0.000055	5.53×10^{-05}	U
Trichoroethylene	0.0000000081	8.08×10^{-09}	U
Vinyl chloride monomer	0.0000000068	6.81×10^{-09}	U
Xylenes (individual or mixed isomers)	0.00000013	1.32×10^{-07}	U

Notes:
1. Original USEPA42 data in lb/MMBTU. Source: Reference 23 and Table 79, Reference 2.
2. Landfill gas composition assumed as 50% CH_4, 27% CO_2, 23% N_2,; Average landfill gas heating value (HHV) of 19.45 MJ/Nm³.
3. Converted to Energy basis using a heat rate of 10,000 kJ/kWh.

Appendix C: 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 17.

The conversion constants below are grouped as follows:

- Power
- Weight
- Volume
- Length
- Other Units.

Table 60: Useful conversion factors in relation to determining emissions from combustion engines

To convert from	To	Multiply by
<u>Power</u>		
hp – horsepower	kW - kilowatts	7.46×10^{-01}
<u>Weight</u>		
kg – kilograms	lb - pounds	$2.21 \times 10^{+00}$
<u>Volume</u>		
UK gallon	m^3 - cubic metres	4.55×10^{-03}
US gallon	m^3 - cubic metres	3.79×10^{-03}
L – litres	m^3 - cubic metres	1.00×10^{-03}
<u>Length</u>		
m – metres	km - kilometres	1.00×10^{-03}
mile	km - kilometres	$1.61 \times 10^{+00}$
<u>Other units</u>		
MMBTU	BTU	$1.00 \times 10^{+06}$
lb/hp-h	kg/kWh	6.08×10^{-01}
BTU	J	$1.05 \times 10^{+03}$

Table 61: Fuel physical properties useful in determining emissions from combustion engines

Fuel	**Description and properties**
Diesel	Also called automotive distillate. Density = $8.361 \times 10^{+02}$ kg/m3 Heating value = 38.21 MJ/L (Source: Reference 7, page 51)
Petrol	Also called motor spirit. Density = $7.391 \times 10^{+02}$ kg/m3 Heating value = 34.36 MJ/L (Source: Reference 7, page 51)
Natural gas	Also called methane. Density = 6.963×10^{-01} kg/Sm3 Heating value = 38.9 MJ/Sm3 (Source: Reference 7, page 51)

Appendix D: Classification of typical vehicles used by Australian industry

Road transport vehicles	
Classification	**Description**
Cars	Small 4 wheel drive (4WD) vehicles such as Suzuki and Daihatsu
	2 wheel drive (2WD) utilities less than tonne
	Other 2WD passenger cars
LGV – light goods vehicle	Large 4WD vehicles such as Toyota Landcruisers and Nissan Patrols
	Non-articulated trucks less than 4 tonnes nett
	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
	Aircraft tug
	Equipment tug

Appendix E: Modifications to the Combustion engines emission estimation technique (EET) manual (October 2003)

Page	Outline of alteration
throughout	Version 3.0 follows the new standard format for emission estimation technique manuals.
	Version 3.0 incorporates the changes to the National Environmental Protection Measure (NEPM) by State and Federal Ministers from June 2007.
	Version 3.0 incorporates new emission factors which are additional or modifications of those used in the October 2003 version of the manual, based on further research reports.