REPORT

LANDSIDE EMISSION INVENTORY FOR THE PORT OF BRISBANE PRECINCT 2007/2008

Port of Brisbane Corporation

Job No: 3267

30 June 2010

A PEL Company

PROJECT TITLE:	LANDSIDE EMISSION INVENTORY FOR THE PORT OF BRISBANE PRECINCT 2007/2008
JOB NUMBER:	**3267**
PREPARED FOR:	Sue Koreman Port of Brisbane Corporation
PREPARED BY:	Robin Smit, Bethany Warren, Mitchell Kelly, James Steele, Kelsey Bawden, Peter Anyon, Hannah O'Reilly, Adam Pekol
APPROVED FOR RELEASE BY:	Robin Ormerod
DISCLAIMER & COPYRIGHT:	This report is subject to the copyright statement located at www.paeholmes.com © Queensland Environment Pty Ltd trading as PAEHolmes ABN 86 127 101 642

DOCUMENT CONTROL

VERSION	DATE	PREPARED BY	REVIEWED BY
01 [Draft]	16.10.09	Robin Smit	Robin Ormerod
02 [Final]	30.06.10	Robin Smit	Robin Ormerod

Queensland Environment Pty Ltd trading as
PAEHolmes ABN 86 127 101 642

BRISBANE:
Level 1, La Melba, 59 Melbourne Street South Brisbane Qld 4101
PO Box 3306 South Brisbane Qld 4101
Ph: +61 7 3004 6400
Fax: +61 7 3844 5858

SYDNEY:
Suite 2B, 14 Glen Street
Eastwood NSW 2122
Ph: +61 2 9874 8644
Fax: +61 2 9874 8904

Email: info@paeholmes.com

Website: www.paeholmes.com

DISCLAIMER

PAEHolmes acts in all professional matters as a faithful advisor to the Client and exercises all reasonable skill and care in the provision of its professional services.

Reports are commissioned by and prepared for the exclusive use of the Client. They are subject to and issued in accordance with the agreement between the Client and PAEHolmes. PAEHolmes is not responsible for any liability and accepts no responsibility whatsoever arising from the misapplication or misinterpretation by third parties of the contents of its reports.

Except where expressly stated, PAEHolmes does not attempt to verify the accuracy, validity or comprehensiveness of any information supplied to PAEHolmes for its reports.

Reports cannot be copied or reproduced in whole or part for any purpose without the prior written agreement of PAEHolmes.

Where site inspections, testing or fieldwork have taken place, the report is based on the information made available by the client or their nominees during the visit, visual observations and any subsequent discussions with regulatory authorities. The validity and comprehensiveness of supplied information has not been independently verified and, for the purposes of this report, it is assumed that the information provided to PAEHolmes is both complete and accurate. It is further assumed that normal activities were being undertaken at the site on the day of the site visit(s), unless explicitly stated otherwise.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Internationally, air emissions from port activities are under increasing scrutiny by regulators and the community. In response, many ports are initiating emission inventories and clean air action plans. This report presents the results of a baseline landside emissions inventory (LEI) for the Port of Brisbane precinct. Both the landside (this report) and waterside (AMC, 2009) emission inventories for Port of Brisbane will define a **baseline** from which to create and implement emission reduction strategies and track performance over time.

The emission inventory has been developed for fuel use, greenhouse gases (CO_2-e, CH_4, N_2O, CO_2) and relevant air pollutants (CO, THC, NO_x, SO_2, PM_{10}, $PM_{2.5}$) for the base year 2007/08. It has estimated emissions for on-road trucks, cargo handling equipment (CHE) and rail.

The fuel consumption and emission factors have been based on empirical Australian data to the extent these are available. Relevant transport activity data was collected and processed from several sources, which include:

- traffic count data, license plate recordings, vehicle registration data, driver surveys, origin-destination surveys, GPS data and weight-in-motion measurements for **trucks**;
- locomotive count data, time in area estimates, train configuration, engine specifications (e.g. rated power, type of fuel), use of emission control technology and driving behaviour (time in notch) for **rail**; and
- equipment type and quantity, total fuel use or total time of operation, engine specifications and use of emission control technology for **CHE**.

Six basic truck types were considered, namely medium and heavy rigid trucks, semi-trailers, B-doubles, light and heavy super B-doubles. A more detailed classification was developed to account for the effects of fuel type (diesel, petrol, LPG, CNG, ULSD, biodiesel) and engine and emission control technology on emissions, which resulted in a total of 630 vehicle classes. The effects on emissions of vehicle operation mode (hot running, idling, cold and hot start), average speed, vehicle loading (empty, half, full) and road grade on emissions were also considered in the emission inventory.

Eight rail processes (e.g. coal, grain, container, shunting) were considered in the emission inventory. The effects on emissions of train operation mode (notch) were considered in the emission inventory.

For CHE, 12 main equipment types were considered, including forklifts, cranes, loaders and reach stackers. A further classification was developed to account for fuel type (diesel, LPG, petrol) and engine and emission control technology, which resulted in a total of 336 CHE classes. The effects on emissions of CHE operation (engine load) were also considered in the emission inventory.

Figure ES.1 summarizes the results of the land-based emission inventory and shows the contribution of each source category to total land-based emission levels.

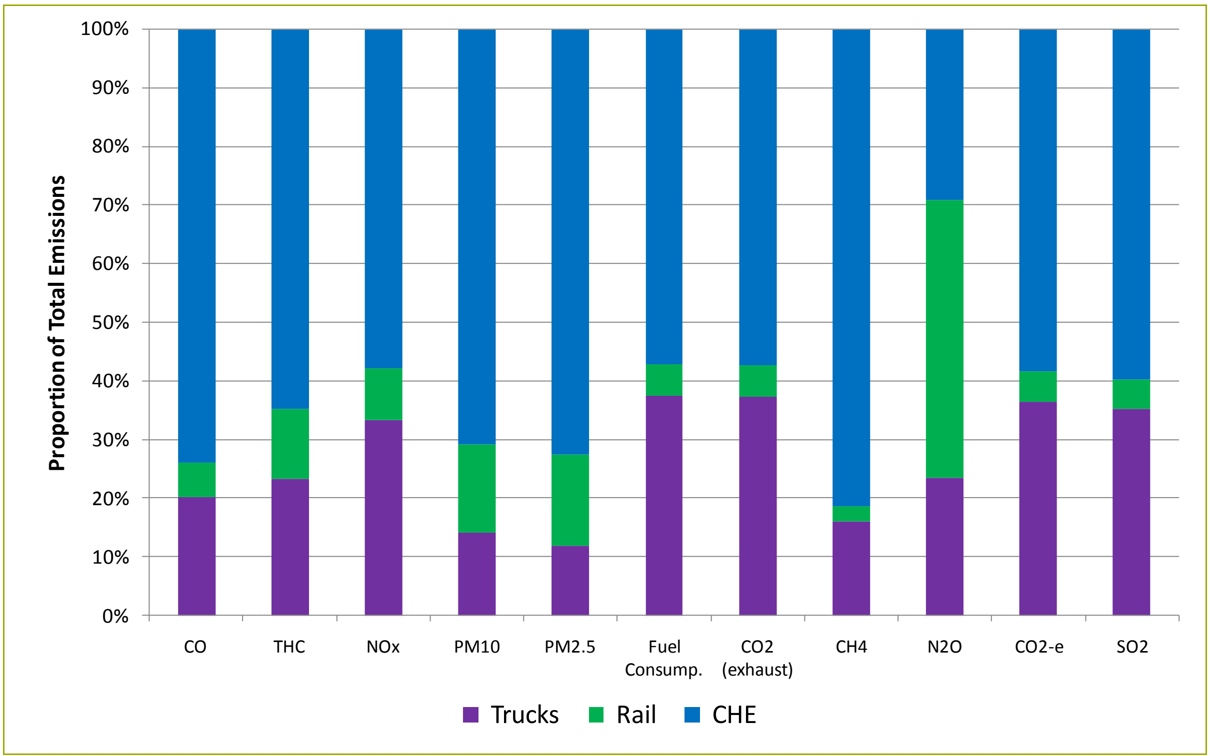


Figure ES.1: Contribution of Land-Based Source Categories to Total Emissions

The LEI indicates that CHE is by far the most important emissions source, as it generally causes the majority (60-80%, depending on the pollutant) of land-based emissions in the study area. This largely explained by the large "activity level" of cargo handling equipment – it is estimated to account for almost 60% of total fuel consumption in the study area – as well as the absence of non-road emission standards in Australia.

The next most important source is 'trucks', which is estimated to account for almost 40% of total fuel consumption and GHGs (CO_2-e) in the study area. However, their contribution to total land-based emissions is typically lower and varies between about 10% to 35%, depending on the pollutant. The relatively low contribution of truck emissions to total land-based emissions is due to their relatively low emission rates. This is because road vehicle emissions are more tightly controlled than non-road sources, which has resulted in better engine optimisation and commonly used emission reduction technologies such as oxidation catalysts and EGR.

Rail is estimated to consume only 5% of total fuel in the study area and, as a result, estimated to produce only 5% of total GHGs (CO_2-e). The contribution to total land-based emissions varies between about 3% to 16%, depending on the pollutant. The relatively large contribution of rail to total emissions of THC, NO_x, PM, and in particular N_2O, is caused by relatively high emission factors.

1 GLOSSARY OF TERMS

Variable	Definition
Semi-trailer (ST)	Austroads Vehicle Classifications 6, 7, 8, 9. See Table 4.2.
Austroads Classification	Classification of on-road vehicles by type, number of axles, etc. according to Austroads. Austroads is the association of Australian and New Zealand road transport and traffic authorities and aims to promote improved road transport outcomes (http://www.austroads.com.au/). For pictures and overview of vehicle classes refer to Table 4.2.
B-Double (BD)	Austroads Vehicle Classification 10. See Table 4.2.
Brake horse power	The net effective power in horse powers, as shown by a friction brake. The power produced by an engine is expressed in horsepower. When the power developed is measured by means of a dynamometer or similar braking device, it is called brake horsepower. This is the power actually delivered by the engine and is therefore the capacity of the engine. One metric horsepower (Hp) equals 0.7355 kilowatts.
CH_4	Methane.
CO_2	Carbon dioxide.
CO_2-e	Carbon dioxide equivalents. CO_2-e is a quantity that describes, for a given mixture of greenhouse gases, the total amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified time scale (generally 100 years). An overview of NGA global warming potential (GWP) values used in this study is presented in Table 3.2.
Cold start	A cold-start is an engine start, which occurs four hours or more after the engine has been turned off for trucks without advanced emission after-treatment systems (e.g. SCR). Cold-start emissions are elevated emissions due to cold engines that burn fuel-rich until the engine temperature is up to normal and (if present) due to reduced catalyst efficiency until the catalyst is brought up to normal operating temperatures.
Fully Loaded Vehicle	Weight = Either GVM or GCM.
GHG	Greenhouse gas (i.e. CO_2, CH_4, N_2O – or combined as CO_2-e).
Gross Vehicle Mass/Weight (GVM or GVW)	The weight of a vehicle including the maximum allowable load as specified by the 'Manufacturer'. GVM now only applies to a "base vehicle", which is either a rigid truck, bus or prime mover with one trailer attached. GVM is vehicle tare weight plus the specified load capacity.
Gross Combination Mass (GCM)	The combined vehicle weight specified by the 'Manufacturer' which is the maximum of the sum of the 'Gross Vehicle Mass' of the drawing vehicle **plus** the sum of the maximum axle loads of all attached units (trailers) that can lawfully be towed.
Half Laden Vehicle	Weight = (GVM|GCM + Empty Weight) x 0.5.
HCV	Heavy Commercial Vehicle (Heavy Rigid Truck)
LHV	The lower heating value (also known as net calorific value or LHV) of a fuel is defined as the amount of heat released by combusting a specified quantity (initially at 25 °C or another reference state) and returning the temperature of the combustion products to 150 °C. The LHV assumes that the latent heat of vaporization of water in the fuel and the reaction products is not recovered. It is useful in comparing fuels where condensation of the combustion products is impractical, or heat at a temperature below 150 °C cannot be put to use. By contrast, the higher heating value (HHV or gross calorific value) includes the heat of condensation of water in the combustion products.
Link based average speed (km/h)	Speed derived from travel time data (not spot speeds).

Variable	Definition
MCV	Medium Commercial Vehicle (Medium Rigid Truck)
NGA	National Greenhouse Accounts.
NO_x	Nitrogen oxides.
N_2O	Nitrous oxide.
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than 2.5 μm.
PM_{10}	Particulate matter with an aerodynamic diameter less than 10 μm.
Rail Line haul Operation	Movement of cargo over long distances, which occurs within the port area as the initiation or termination of a line haul trip.
Rigid Truck	Austroads Vehicle Classifications 3, 4, 5. See Table 4.2.
Road gradient (%)	Road gradient expressed as % grade.
Rail Shunting	Assembling and disassembling of trains, sorting and (re)-arranging the order of railcars and short distance hauling of rail cargo.
SO_2	Sulphur dioxide.
Super B-Double (SBD)	Austroads Vehicle Classification 10. See Table 4.2. A Super B-double is a B-double which is capable of carrying 4 x 20 foot containers or 2 x 40 foot containers, and which exceeds some regulation dimensions and mass limits. There are two types of Super B-doubles: 1) A 'heavy' Super B-double with an 'A' quad axle trailer used for carrying full containers, and A 'light' Super B-double, with either a single or tandem drive prime mover and two tandem axle trailers, used for carrying empty containers only. The operation of Super B-doubles is restricted to nominated routes within the Port of Brisbane precinct.
Tare Weight	The weight of an un-laden vehicle (not a trailer) including equipment and accessories necessary for the normal operation of the vehicle (e.g. fuel, water, lubricants and tools).
THC	Total Hydrocarbons.
ULSD	Ultra-low sulphur diesel with a maximum of 10 ppm sulphur.
VKT	Vehicle kilometers travelled.

2 INTRODUCTION

PAEHolmes was commissioned by Port of Brisbane Corporation to develop a baseline landside emissions inventory (LEI) for the Port of Brisbane precinct (Figure 2.1 provides a bird's eye view of the port area).

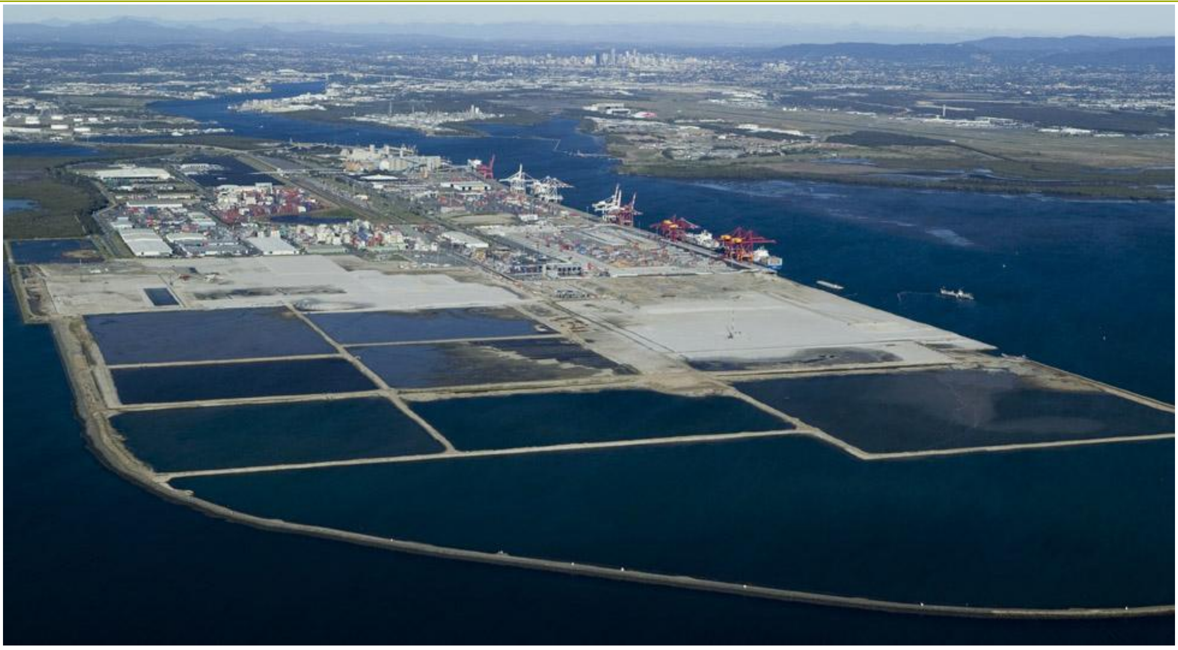


Figure 2.1: Bird's Eye View of Port of Brisbane

This report presents the final results of the project and it has refined an initial (Phase 1) study that was conducted in 2009 (PAEHolmes, 2009). For the purpose of improved readability, the large number of emission factors for both cargo handling equipment (CHE) and on-road trucks are not included in this report. They are provided in separate spreadsheets:

- "Truck emission factors PBC LEI 2007-2008.xls"; and
- "CHE emission factors PBC LEI 2007-2008.xls".

2.1 Background

Trade through the Port of Brisbane has increased in the last 10 years, leading to the expansion of port facilities. In turn, activity with respect to ships, on-road vehicles, rail and cargo handling equipment has also increased, which has likely resulted in higher greenhouse gas and air contaminant emissions.

Internationally, air emissions from port activities are under increasing scrutiny by regulators and the community. In response, many ports are initiating emission inventories and clean air action plans. Consistent with this worldwide development, the Port of Brisbane Corporation is commissioning emission inventories for waterside (AMC, 2009) and landside activities at the port (this report). The inventories will define a **baseline** from which to create and implement emission reduction strategies and track performance over time.

Rather than inventorying all the emissions associated with all port activities, the inventories seek to identify those emissions which the Corporation may be able to influence through future strategies. The overall inventory project will examine ocean-going vessels, trucks, rail and cargo handling equipment.

2.2 The Study Area

Figure 2.2 shows the geographic boundary of the study area. It includes Fisherman Islands, Whyte Island, Port Gate, Caltex and west to the junction of Port Drive and Lytton Road.

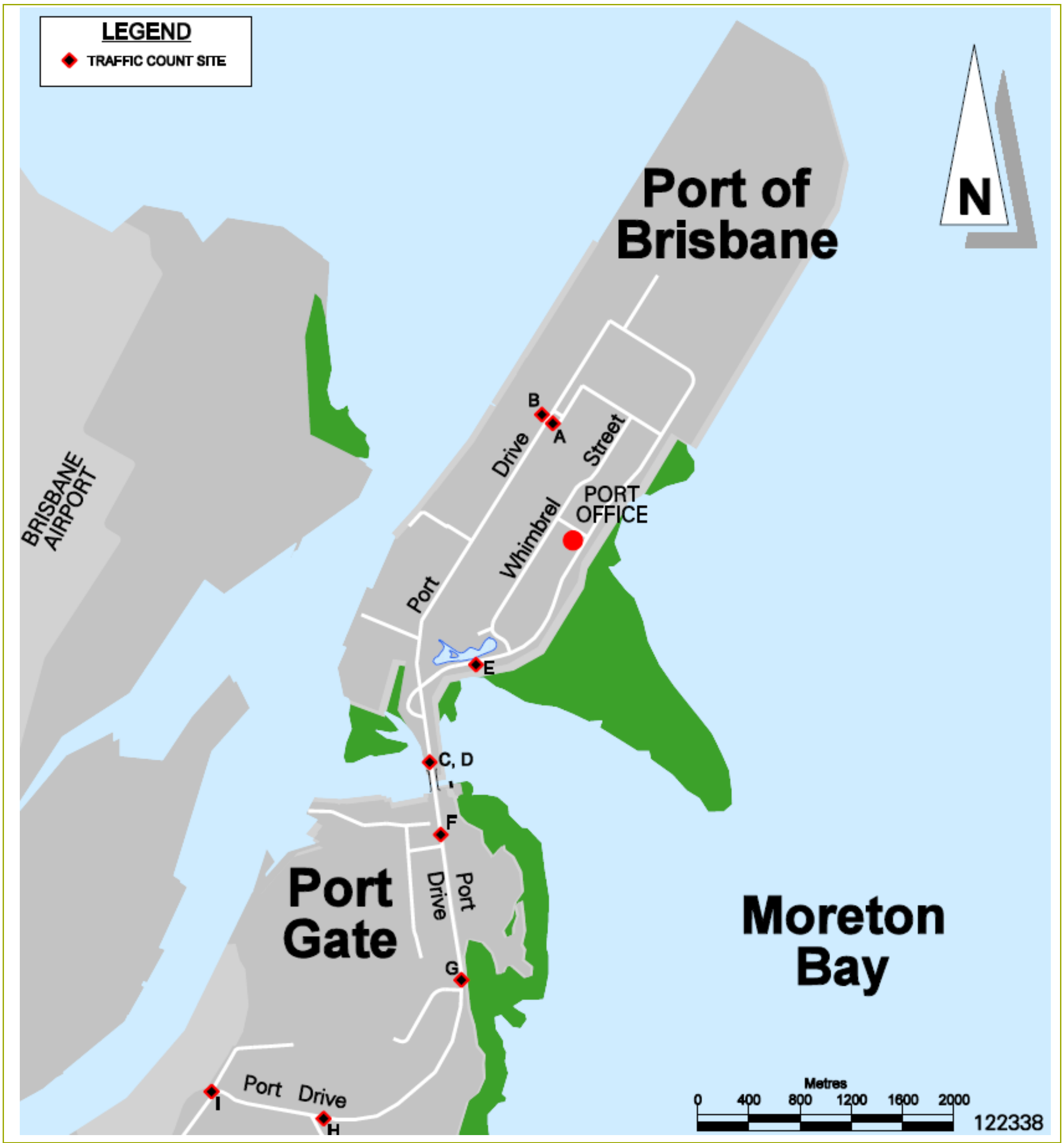


Figure 2.2: Geographic Boundary of the Study Area

Figure 2.3 provides an aerial view of the port area.

Figure 2.3: Aerial View of Port of Brisbane

2.3 Objectives of Study

The aim of this project is to develop a baseline landside emissions inventory (LEI) for greenhouse gases (**CO_2-e, CH_4, N_2O, CO_2**) and relevant air pollutants (**CO, THC, NO_x, SO_2, PM_{10}, $PM_{2.5}$**)[a] for the Port of Brisbane for the base year 2007/08. The focus is on emissions that can be attributed to:

- roads and rail to and from Port operators' facilities; and
- cargo and bulk handling equipment within Port operators' facilities.

The LEI will:

- provide insight into the relative importance of the effect of landside activities on emissions;
- guide the development of emission reduction strategies;
- provide a baseline from which to monitor progress of port emissions in time;
- estimate emissions for specific years after 2007/2008;
- facilitate impact assessment of emission reduction measures;
- permit emissions forecasts (scenario testing); and
- provide (to some extent) input to air quality assessments.

[a] It is possible to develop the LEI for a large number of air pollutants. For instance, our road traffic emissions model can predict emissions for 98 pollutants. For specific applications, such as local air quality modelling, it is generally recommended to be comprehensive. We do not believe this is necessary here given the objectives of this study. To be cost-effective we have included the main greenhouse gases and air pollutants in this project.

2.4 Scope of Work

The project includes the following tasks:

- Determination of Port activity for on-road trucks, rail and cargo handling equipment.
- Determination of emission factors for on-road trucks, rail and cargo handling equipment.
- Combining activity and emissions information into an inventory.

The actual methods and data used in this process are discussed in more detail in the next sections. The scope of this work is <u>not</u> to be **comprehensive** and **detailed** with respect to:

- inclusion of all relevant sources;
- coverage of the actual road network in the study area; and
- spatial and temporal distribution of emissions within the study area.

Rather, the aim is to identify relevant sources which Port of Brisbane Corporation may be able to influence through future strategies, using the available activity field data to compute total emission loads for the study area. We appreciate that this approach is a cost-effective way of meeting the objectives, but we note that it may impose some limitations on the use of the LEI for other purposes, such as the assessment of local air quality in the study area.

Three sources of emissions within the port precinct were excluded from this study scope but warrant acknowledgement here:

- *LDVs*: travel of on-road light-duty vehicles (LDVs) such as cars and light commercial vehicles.
- *Vehicle travel within the Vehicle Precinct*: over 200,000 vehicles were offloaded in 2007/2008 base year from ships at the port. While some are directly transported off-island, the majority remain on island and are each driven 1 to 2 kilometers within the vehicle precinct during the pre-delivering inspection process. The PBC estimates this may total 330,000 km, which is about 2% of total estimated VKT for trucks, as will be discussed later in this report.
- *Earth and civil works projects*: heavy equipment undertaking earth and civil works projects for the Port of Brisbane Corporation on Fisherman Islands. While some equipment is owned by PBC, most is contracted as part of the future port expansion, wharf, road and other infrastructure projects.

The LEI development process was divided into two main steps. As a **first step**, the available activity data were collected, examined and reviewed for each source type. The review of the activity data was conducted from the perspective of the available and most appropriate emission factors. A general point that applies to all sources is that, in the absence of relevant (aspects of) activity data, reasonable assumptions were made to enable development of the LEI. As a **second step**, the activity data were combined with the appropriate emission factors to develop the LEI.

3 DEFINITIONS

This chapter presents an overview of relevant input data (e.g. conversion factors).

3.1 Fuel Parameters

An overview of fuel parameters used in this study is presented in Table 3.1.

Table 3.1: Fuel Characteristics

Fuel Type	Density kg/l	LHV MJ/kg	GHG Emission Factor * g CO_2-e/g	Sulphur Content ppm-m
Diesel	0.83	43.0	3.251 / 3.246 / 3.244 [1)]	50
Petrol	0.73	44.3	3.261 / 3.135 [2)]	100
LPG	0.54	46.1	2.958 / 2.929 [2)]	100
CNG (200 bar)	0.16	49.4	2.538	100
ULSD	0.83	43.0	3.251	10
Biodiesel	0.88	36.8	0.134	10

* These values have been derived from DCC (2008), p. 16-17.

[1)] Value for pre-ADR 80/00 vehicles / ADR 80/00 vehicles / post-ADR 80/00 vehicles.

[2)] Value for pre-ADR 80/00 vehicles / ADR 80/00 vehicles and onwards

3.2 Air Pollutants

Air pollutants are airborne substances that occur in concentrations high enough to cause adverse effects on health, the environment and/or outdoor structures (amenity, property, cultural). Air pollutants can affect health in different ways and in varying degrees of severity ranging from minor irritation through serious illness to premature death. Although thousands of air pollutants can be identified, most of them can be classified in the following major groups according to their origins and formation processes:

- products of incomplete combustion, including carbon monoxide (CO), particulate matter (PM) and hydrocarbons (HCs);
- products of high-temperature combustion processes, including nitrogen oxides (NO_x);
- by-products of combustion due to impurities in the fuel, including heavy metals and sulphur oxides (SO_x);
- non-combustion products, including evaporative hydrocarbons;
- secondary air pollutants such as photochemical oxidants, including tropospheric ozone and peroxyacetyl nitrate; and
- greenhouse gases, including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).

Some more information on specific air pollutants is provided below.

Carbon monoxide (CO)

Carbon monoxide is produced from incomplete combustion of fuels, where carbon is only partially oxidised instead of being fully oxidised to form carbon dioxide. Carbon monoxide can be harmful to humans because its affinity for haemoglobin is more than 200 times greater than that of oxygen. When it is inhaled it is taken up by the blood and therefore reduces the capacity of the blood to transport oxygen. This process is reversible. Symptoms of carbon monoxide intoxication are lassitude and headaches. These symptoms are generally not reported until relatively high ambient atmospheric concentrations are reached.

Oxides of nitrogen (NO_x)

Oxides of nitrogen are produced when fossil fuel is combusted in internal combustion engines (e.g. motor vehicles). Nitrogen oxides (NOx) emitted by fossil fuel combustion are comprised mainly of nitric oxide (NO) and nitrogen dioxide (NO2). NO is much less harmful to humans than nitrogen dioxide and is not generally considered a pollutant at the concentrations normally found in urban environments. Typically, close to the roadways, NO2 would makes up 5 to 20 per cent by weight of the total oxides of nitrogen.

Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infections such as influenza. The effects of short-term exposure are still unclear, but continued or frequent exposure to concentrations that are typically much higher than those normally found in the ambient air may cause increased incidence of acute respiratory illness in children. Concern with NO is related to its transformation to NO2 and its role in the formation of photochemical smog. Nitrogen oxides in the air are a potentially significant contributor to a number of environmental effects such as acid rain and eutrophication.

Particulate matter (PM_{10}, $PM_{2.5}$)

Ambient aerosols are known as PM, short for Particulate Matter. Depending on the diameter or size of the particles, they are termed PM_{10} (for particles with diameters of up to approximately 10 micrometres) or $PM_{2.5}$ (for those less than 2.5 micrometres in diameter). Particulate Matter (PM) in the ambient air can lead to health effects and even to premature mortality. This result has been found in a score of epidemiological studies, but its cause is not yet clear. Fine particles with an aerodynamic diameter less then 10 μm (PM_{10}, $PM_{2.5}$) can enter bronchial and pulmonary regions of the respiratory tract. The health effects of particulate matter are complicated by the chemical nature of the particles and by the possibility of synergistic effects with other air pollutants such as sulphur dioxide.

Particulate matter is emitted due to incomplete combustion of fuels, additives in fuels and lubricants, worn material that accumulates in the engine lubricant, and brake and tyre wear. $PM_{2.5}$ constitutes both primary particles, such as diesel soot and volcanic ash, and secondary aerosols, particles formed in the atmosphere from chemical reaction of gaseous species.

Sulphur dioxide (SO_2)

Sulphur dioxide belongs to the family of sulphur oxide gases (SO_x). These gases are formed when for instance fuel containing sulphur (mainly coal and oil) is burned. The major health concerns associated with exposure to high concentrations of SO_2 include effects on breathing, respiratory illness, alterations in pulmonary defences, and aggravation of existing cardiovascular disease. SO_2 is a major precursors to acid rain, which is associated with the acidification of lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility.

Total hydrocarbons (THC)

Total hydrocarbons comprise of a collection of various organic components, and several of these compounds may not be toxic. THC include certain air toxics such as benzene, 1,3-butadiene, toluene and xylenes. Air toxics are present in the air in low concentrations with characteristics such as toxicity or persistence so as the be hazard to human, plant or animal life. There is evidence that cancer, birth defects, genetic damage, immune-deficiency, respiratory and nervous system disorders can be linked to exposure to occupational levels or air toxics. THC also include reactive organic compounds, comprising mainly hydrocarbons that contribute to the formation of photochemical smog and organic aerosols (which add to atmospheric particle loading).

Greenhouse gases (GHGs)

Greenhouse gases are gases in an atmosphere that absorb and emit radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The main greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone. Carbon Dioxide (CO_2) and much smaller amounts of N_2O and Methane (CH_4) are emitted when fossil fuels are combusted. They all contribute directly to total greenhouse gas emissions, although they have different global warming potentials. CO_2-e (CO_2 equivalents) is a quantity that describes, for a given mixture of greenhouse gases, the total amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified time scale (generally 100 years).

An overview of global warming potential (GWP) values used in this study is presented in Table 3.2. These values were taken from DCC (2008, p. 51).

Table 3.2: Global Warming Potential Values

Pollutant	GWP -
CO2	1
CH4	21
N2O	310

4 TRUCKS

Despite great successes in reducing exhaust emissions from motor vehicles over the past decades, the emissions from road transport activities still make a significant contribution to air quality problems at a range of scales. Issues of concern include localised exposure to air pollutants in heavy traffic areas, total emission loads and global warming. In consideration of overseas studies (e.g. Starcrest, 2007), truck emissions are expected to be a major source of emissions in the LEI.

Truck emissions are a function of:

- "**truck activity**", which involves the total number of vehicle kilometers travelled (VKTs), the amount of time spent idling and the number of starts that have been made; and
- **fuel consumption and emission rates**, and the factors that influence them such as fleet composition and the way vehicle are driven (e.g. high speed, low speed, stop-and-go driving, etc.).

One important notion is that road traffic in the Port area has a significantly different vehicle fleet profile as compared to the average urban fleet profile in Queensland. For instance, the fleet is characterized by a relatively large proportion of heavy-duty vehicles. As will be discussed later in this section, trucks make up about 40% of the registered vehicle fleet passing the Captain Cook bridge, which compares to an average of 4% trucks in the Queensland fleet (ABS, 2007). There are also heavy vehicle configurations that are specific to the Port area. In addition to the common semi-trailer (Figure 4.1), there are B-doubles (Figure 4.2) and light and heavy super-B-doubles (Figure 4.3) which are only allowed to operate in the Port area.

Figure 4.1: A Semi-Trailer

Figure 4.2: A B-Double

Figure 4.3: A Super-B-Double

This section will first discuss the Port area basic vehicle classes and their characteristics in more detail (section 4.1), then the different aspects of truck activity (section 4.2), subsequently a discussion of emission factors (section 4.3) and finally present the results of the truck emission inventory (section 4.4).

4.1 Classification of Trucks and Fleet Characteristics

For the emission inventory a fleet breakdown is needed with a sufficient level of detail to reflect factors or variables that have a significant impact on emission levels. This means that a breakdown is required in terms of:

1) basic vehicle type (as presented in Table 4.1, see below);
2) fuel type (petrol, diesel, etc.); and
3) engine and emission control technology.

Table 4.1 provides an overview of the six basic vehicle types that are considered in this study and their definitions in terms of vehicle configuration (number of axles), empty weight (mean) and maximum laden weight (mean). This classification – and not for instance the more commonly used *Austroads* classification – had to be used because it enables the use of available empirical emissions data, as will be explained in more detail later.

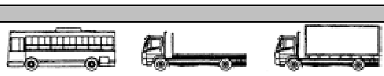
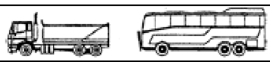
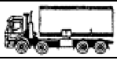
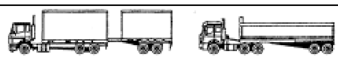
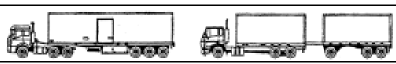
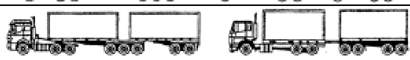
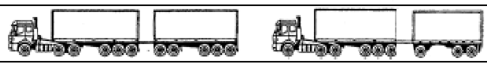
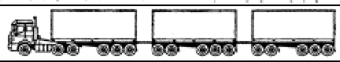
Table 4.1: Basic Truck Classification – Austroads, Weight and Axle Definitions

Basic Vehicle Type	Austroads Class 1)	DTMR Class 4)	Number of Axles	Empty Weight	Maximum Laden Weight
Rigid Truck – Medium Commercial Vehicle (MCV) "2 axle groups, ≥ 2 axles", No Trailer(s)	3, 4, 5	Trucks	Mean: 2 Range: 2	Mean: 3.6 tonne Range: 2.2-5.4 tonne	Mean: 6.4 tonne (GVW) Range: 3.5-12.0 tonne (GVW)
Rigid Truck – Heavy Commercial Vehicle (HCV) "2 axle groups, ≥ 2 axles", No Trailer(s)	3, 4, 5	Trucks	Mean: 3 Range: 3-4	Mean: 7.4 tonne Range: 5.4-10.6 tonne	Mean: 16.2 tonne (GVW) Range: 12.0-25.0 tonne (GVW)
Semi-trailer (ST) "3 axle groups, ≥ 3 axles ", 1 Trailer	6, 7, 8, 9	Prime Mover	Mean: 5 Range: 3-6	Mean: 13.8 tonne Range: 10.6-15.1 tonne	Mean: 38.0 tonne (GVW) Range: 25.0-40.0
B-Double (BD) "4 axle groups, 7-9 axles", 2(+) Trailers	10	B-double	Mean: 8 Range: 7-9	Mean: 20 tonne Range: 15.1-23 tonne	Mean: 55.5 tonne (GCM) Range: 40.0-70.0 tonne (GCM)
Light Super B-Double (SBD) "4 axle groups, 6 axles", 2(+) Trailers 2)	10 3)	B-triple, Road Train	Mean: 6 Range: 6	Mean: 17 tonne Range: 15-18 tonne	Mean: 25.0 tonne (GCM) Range: 22.0-32.0 tonne (GCM)
Heavy Super B-Double (SBD) "4 axle groups, ≥ 10 axles", 2(+) Trailers	10 3)	B-triple, Road Train	Mean: 10 Range: 10	Mean: 25 tonne Range: 23-26 tonne	Mean: 85.0 tonne (GCM) Range: > 70-109.0(+) tonne (GCM)

1) Refer to Table 4.2.
2) The light SBD is intended for use with empty containers only.
3) SBDs do not appear in the Austroads classifications as they are new vehicles and only exist at the Port.
4) Refer to section 4.2.3.

Table 4.2 presents an overview of Austroads definitions (http://www.transport.sa.gov.au/transport_network/facts_figures/traffic_pdfs/austroads_classes.pdf).

Table 4.2: Austroads Classification

Level 1 Length (Indicative)	Level 2 Axles and Axle Groups		Level 3 Vehicle Type	AUSTROADS Classification		
Type	Axles	Groups	Typical Description	Class	Parameters	Typical Configuration
					LIGHT VEHICLES	
Short up to 5.5m		1 or 2	Short Sedan, Wagon, 4WD, Utility, Light Van, Bicycle, Motorcycle, etc	1	d(1) ≤ 3.2m and axles = 2	
Medium 5.5m to 14.5m	3, 4 or 5	3	Short - Towing Trailer, Caravan, Boat, etc	2	groups = 3 d(1) ≥ 2.1m, d(1) ≤ 3.2m, d(2) ≥ 2.1m and axles = 3, 4 or 5	
					HEAVY VEHICLES	
	2	2	Two Axle Truck or Bus	3	d(1) > 3.2m and axles = 2	
	3	2	Three Axle Truck or Bus	4	axles = 3 and groups = 2	
	> 3	2	Four Axle Truck	5	axles > 3 and groups = 2	
Long 11.5m to 19.0m	3	3	Three Axle Articulated Three axle articulated vehicle, or Rigid vehicle and trailer	6	d(1) > 3.2m, axles = 3 and groups = 3	
	4	> 2	Four Axle Articulated Four axle articulated vehicle, or Rigid vehicle and trailer	7	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 4 and groups > 2	
	5	> 2	Five Axle Articulated Five axle articulated vehicle, or Rigid vehicle and trailer	8	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 5 and groups > 2	
	≥ 6	> 2	Six Axle Articulated Six axle articulated vehicle, or Rigid vehicle and trailer	9	axles = 6 and groups > 2 or axles > 6 and groups = 3	
Medium Combination 17.5m to 36.5m	> 6	4	B Double B Double, or Heavy truck and trailer	10	groups = 4 and axles > 6	
	> 6	5 or 6	Double Road Train Double road train, or Medium articulated vehicle and one dog trailer (M.A.D.)	11	groups = 5 or 6 and axles > 6	
Large Combination Over 33.0m	> 6	> 6	Triple Road Train Triple road train, or Heavy truck and three trailers	12	groups > 6 and axles > 6	

Definitions:
Group: Axle group, where adjacent axles are less than 2.1m apart
Groups: Number of axle groups
Axles: Number of axles (maximum axle spacing of 10.0m)

d(1): Distance between first and second axle
d(2): Distance between second and third axle

4.2 Activity Data

Vehicle Kilometres Travelled (VKT), idle time, and the number of hot and cold starts were calculated for trucks on the Port of Brisbane road network. This was done in greater detail than in Phase 1 of the project. Many of the assumptions made during Phase 1 were refined using observed data specific to the study area. The geographical extent of the road network adopted for this part of the work is demonstrated in Figure 4.4.

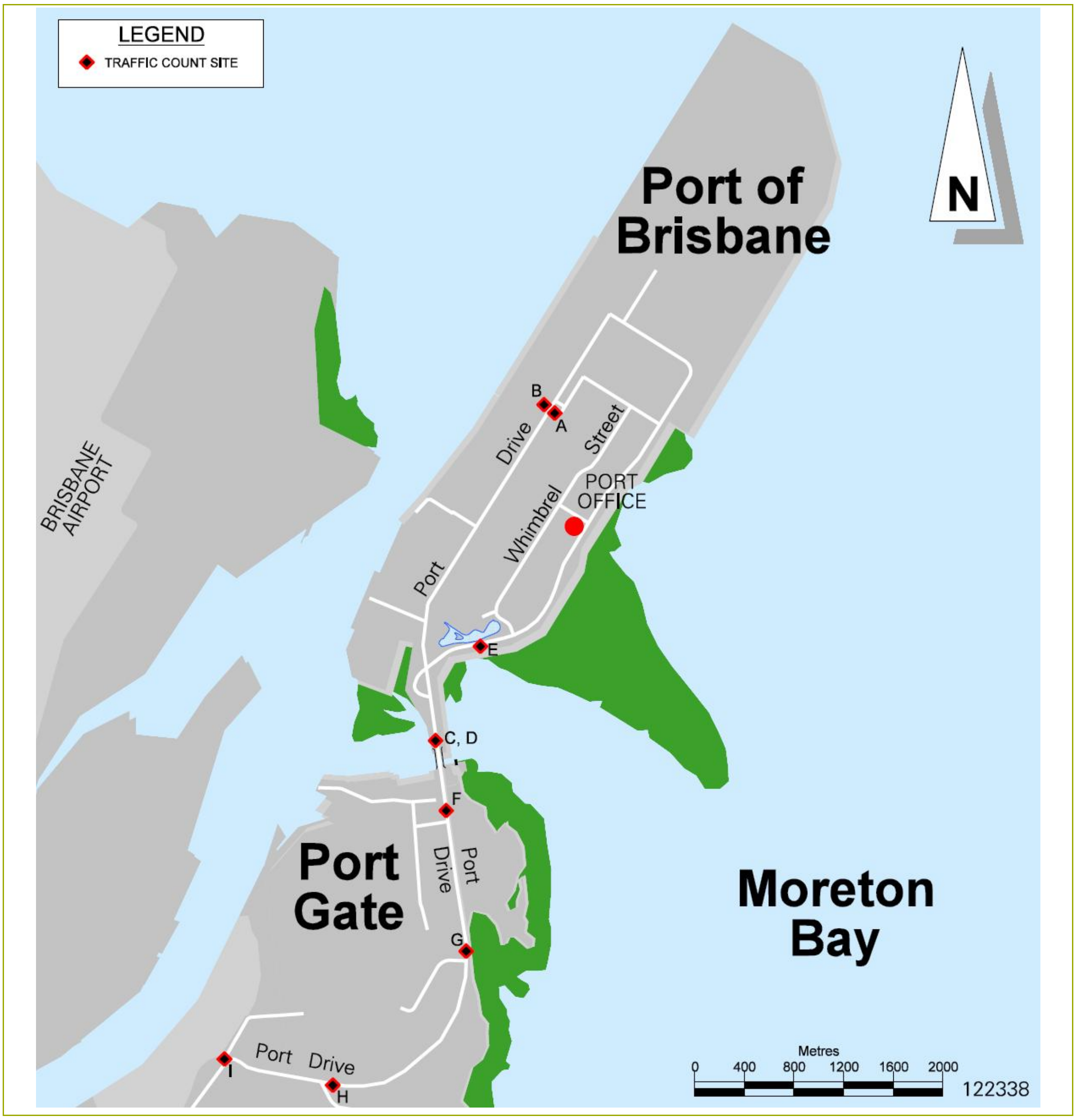


Figure 4.4: Port of Brisbane Road Network

VKT, idle time and number of hot and cold starts were estimated for each combination of:

- basic vehicle class (MCV, HCV, semi-trailer, B-double, light and heavy Super B-double);
- fuel type (diesel and petrol);
- model year/age group or emission standard (ADR) category (pre-1990 'Uncontrolled', 1990-1996 'ADR 30/00', 1997-2002 'ADR 70/00', 2003-2007 'ADR 80/00', 2008-2010 'ADR 80/02'); and
- vehicle loading ('empty', 'half-Laden', 'full').

4.2.1 Overview of Data Sources

The work was undertaken using existing data and data collected specifically for the purpose of this inventory. Table 4.3 (next page) shows the data sources used for truck activity in terms of the geographic scope, temporal scope, currency and availability of the data, and the information that it provides.

4.2.2 Determination of VKT

4.2.2.1 The overall process

The calculation of yearly VKT was undertaken in a number of stages, as follows:

- Firstly, all of the available traffic count data from the various sources listed in Table 4.3 were collated and factored to reflect a common base year (i.e. 2007/08).
- Next, information supplied by the bulk operators was used to estimate the number of truck trips to/from the port associated with these uses (i.e. off-island bulk operator trips).
- The latter were then subtracted from the traffic counts at key control points, such as the Captain Bishop Bridge, to estimate the number of non-bulk operator related trips going to/from the port (i.e. off-island non-bulk operator trips).
- The latter were then subtracted from other traffic counts to estimate the number of on-island trips. Figure 4.5 (next page) demonstrates how the preceding three steps relate to one another and the available traffic count data for a particular point on the study area network.
- The resultant estimated truck trips on each link of the study area road network were then multiplied by the corresponding link length to estimate VKT.
- Finally, the resultant estimates of average daily VKT were multiplied by 365 to estimate annual VKT on the study area road network.

Key aspects of this process are discussed in more detail in the next sections.

Table 4.3: Overview of Data Sources for This Study

Data Source	PAEHolmes Fleet Composition Model 2007	GPS Mapping of POB Roads	DMR Traffic Counts	POB OD Survey	POB Classified Traffic Counts	WIM Data	QT Rego Data	Operator Data	Driver Surveys	Speed Survey	GPS Data
Geographic Scope	Brisbane	POB Specific	2-3 points on approaches to POB and Kite street roundabout	POB Specific	2-3 points within POB area	1 point at POB entry	POB Specific	POB Specific	POB Specific	POB Specific	POB Specific
Temporal Scope	Annual	N/A	Hourly for 1 - 7 days	By hour and day for 2 weeks	Hourly for three days	By hour. By day for whole year	By hour and day	By half day for 2 weeks	2-3 days	1 day	By time of day and DOW
Currency	2007	2009	2006 - 2008	2007	2006/07 and 2009	2007/07	2009	2009	2009	2009	2009
Basic Vehicle Classification (not BD, SBD)	x		x		x	x	x	x	x		
Fuel Type	x						x				
Year of Manufacture	x						x				
GVM (Maximum Truck Weight)						x	x		x		
Retro-Fit Technology								x	x		
Proportion Bob-Tailed Trucks						x			x		
VKT		x	x	x	x	x		x	x		
Number of Starts								x			x
Proportion Cold/Hot Engine Start									x		x
Idle (including Proportion Engine Off)									x		x
Vehicle Loading						x					
Average Speed										x	x
Road Grade		x									
Second x Second Speed-Time Data										x	x

4.2.2.2 Collate Traffic Counts

Classified count data on each link was multiplied by link length to get VKT by vehicle class across the whole study area for an average day. "Classified" refers to the Austroads classification (refer to Table 4.2, page 11). Figure 4.4 (page 12) shows the locations of the traffic count sites in the study area. VKT was calculated on a link-by-link basis and then aggregated up to the study area level. It is noted that other activity data such as the idle time and the number of hot and cold starts, were not link-specific and therefore were estimated at the study area level, as will be discussed later. The breakdown of VKT data was based on traffic counts obtained at the following locations:

- Bingera Drive (East of Port Drive) classified 12 hour weekday counts April 2009;
- Port Drive (North of Bingera Drive) classified 12 hour weekday counts April 2009;
- Kite Street / Port Drive DMR classified intersection count: 12 hour weekday 2006;
- Tanker Street / Port Drive DMR classified intersection count: 12 hour weekday 2007;
- Pritchard Street / Port Drive DMR classified intersection count: 12 hour weekday 2007;
- Lytton Road / Pritchard Street DMR classified intersection count: 12 hour weekday 2007;
- Captain Bishop Bridge classified 12 hour weekday counts April 2009;
- WIM site from DMR, classified count data for 5 weekdays in April 2009; and
- Lucinda Drive (West of Whimbrel Street) weeklong tube count April 2009.

Any un-classified counts were split into the 12 AUSTROADS classes using the percentage splits by vehicle class observed at the WIM site and the various classified traffic count sites. In order to break these down into the six basic vehicle types (MCV, HCV, ST, BD, SBD-light, SBD-heavy), the following steps were undertaken:

- for MCVs and HCVs, the relative proportions were derived from a detailed analysis of the WIM and DTMR data (which will be discussed in section 4.2.3); and
- for B-Doubles and Super B-Doubles, the relative proportions for on-island travel were derived from classified traffic count data and a detailed analysis of origin-destination (O/D) data supplied by SD+D Consult (SD+D, 2010 – these data are discussed further in section 4.2.2.5).

An overview of these splits is shown in Table 4.4.

Table 4.4: Split of Rigid Trucks, B-Doubles and Super-B-Doubles

Emission Factor Truck Class	Classification Splits *	Source of Split
On-Island Travel		
MCV	27% of Total Rigid Trucks (Austroads Class 3,4,5)	WIM/DTMR data
HCV	73% of Total Rigid Trucks (Austroads Class 3,4,5)	WIM/DTMR data
ST	Total of Austroads Classes 6,7,8,9	-
BD	46% of Total Austroads Class 10	Classified Count Data, SD+D O/D Data
SBD	54% of Total Austroads Class 10	Classified Count Data, SD+D O/D Data
Off-Island Travel		
MCV	27% of Total Rigid Trucks (Austroads Class 3,4,5)	WIM/DTMR data
HCV	73% of Total Rigid Trucks (Austroads Class 3,4,5)	WIM/DTMR data
ST	Total of Austroads Classes 6,7,8,9	-
BD	98% of Total Austroads Class 10	Classified Count Data, SD+D O/D Data
SBD	2% of Total Austroads Class 10	Classified Count Data, SD+D O/D Data

* Austroads Classes 1 and 2 are cars and cars with trailers – these vehicles are outside the scope of this study. Classes 11 and 12 are road trains, which are not legal on the Metropolitan road network.

4.2.2.3 Factor Traffic Counts

A number of corrections were performed with the traffic count data to get VKT data for the base year 2007/08:

- All traffic counts were factored to a common base year of 2007/08 using *annual growth factors* based on annual container movements and total tonnes into and out of the port over the last three years. Traffic counts from the 2006/07 year were factored up by **9.7%** while counts from the 2008/09 year were factored down by **0.3%**.
- The following *expansion factors* were derived from the data collected at the WIM site to convert counts into yearly totals:
  - 12hr to full weekday: **1.29**;
  - weekday to average full week: **5.43**; and
  - average full week to yearly: **52**.

4.2.2.4 Bulk and Non-Bulk Operator Trips

Truck operator data were supplied, which enabled the trips to and from bulk operators across the Captain Bishop Bridge to be calculated. These volumes were subtracted from the total trips across the bridge to calculate non-bulk operator trips. These were then distributed on other links throughout the study area in proportion to the volumes from the other traffic count sites. The distinction between bulk and non-bulk operator trips was made as bulk operator trips go only on and off the island. Once this distinction was made, the more complex journeys made by non-bulk trips could be accounted for. This was done separately for each vehicle class. Figure 4.5 provides an example of how this calculation was performed for a particular link in the road network.

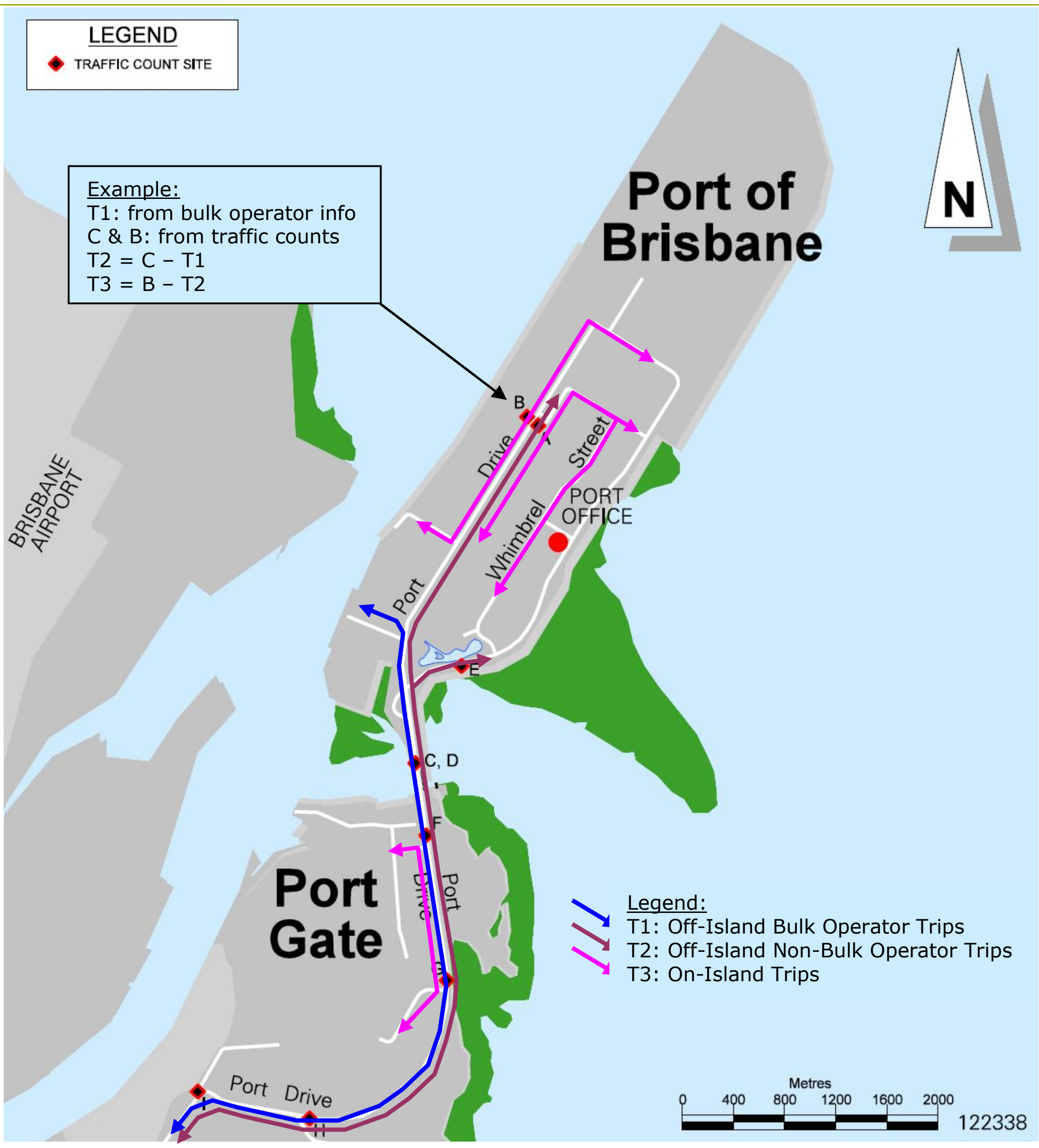


Figure 4.5: VKT Estimation Process

4.2.2.5 *On-Island VKT Check*

The estimate of on-island VKT derived from the above process was checked against origin-destination (O/D) data supplied by SD+D Consult (SD+D, 2010). In doing so, it is important to note that the O/D data supplied by SD+D Consult pertains only to a *portion* of the total on-island truck traffic (i.e. container trucks) and as such can at best provide a lower bound estimate of on-island VKT. The trips in the O/D matrix supplied by SD+D Consult were first doubled (to account for each truck's return journey, presumably without a container) and factored up to an average year. This adjusted truck trip matrix was then multiplied by a matrix of travel distances between each O/D pair to estimate annual on-island VKT.

The SD+D report also provided information on vehicle class for the vehicles travelling between these origins and destinations. The average percentage split to/from each origin/destination area was used to classify semi-trailers, B-Doubles and Super B-Doubles. As noted above the SD+D data did not include information on rigid trucks or the difference between light and heavy Super B-Doubles. The total on-island VKT estimated using this process was found to be significantly less (54%) than that calculated using the method described at the start of Section 4.2.2, as shown in Table 4.5. Table 4.5 also shows the relative proportions of the three basic vehicle classes for each approach within brackets.

Table 4.5: On-Island VKT Check (using SD+D data)

Approach	ST	BD	SBD	Subtotal
Original Approach	1,182,899 (67%)	358,659 (20%)	235,997 (13%)	1,777,555
O/D Matrix Check (SD+D)	621,330 (76%)	60,564 (7%)	131,169 (16%)	813,063

This suggests that the on-island VKT is more than that estimated from the O/D data and probably closer to that estimated from the traffic count data (our approach). Furthermore, while the proportion of all on-island articulated vehicle travel by Super-B-Doubles was roughly the same for both methods (i.e. 13-16%), the O/D data implied a significantly lower proportion of on-island travel by (normal) B-Doubles. It is noted that we have used the relative proportions of BD and SBD from the SD+D data in our approach to estimate on-island VKT (refer to Table 4.4).

4.2.3 Derivation of a Further Breakdown in Vehicle Classes

As the breakdown in the six basic vehicle types is not sufficient for computation of emissions, further work was required to achieve a further breakdown of the on-road fleet in the Port Area with respect to fuel type and engine/vehicle technology type (year of manufacture). This work is summarized in this section and a more detailed discussion is provided in Appendix F.

In order to obtain a detailed breakdown of the vehicle fleet that operates in the Port area, we initially analysed two datasets that were provided by the Department of Transport and Main Roads (**DTMR**):

- license plate numbers by date/time of day recorded with a camera at the WIM facility; and
- vehicle registration details for the recorded license plate numbers (Queensland Transport).

The vehicle registration data, which contained information on vehicle type, fuel type, year of manufacture and GVM/GCM, were then combined with the camera data using license registration as the vehicle identifier. However, the combined camera-registration data only provide information about how vehicles are registered, but they do not provide information how the vehicles are actually used in practice.

Therefore, as an additional task, WIM (weight-in-motion) data were analysed through examination of *Austroads* vehicle class, in-use vehicle mass and, importantly, vehicle configuration (i.e. number of axles by number of axle group, e.g. "1233"). Analysis of camera, vehicle registration and WIM data together resulted in the desired outcome.

The analysis provided a snapshot of the local fleet composition at the WIM site and revealed a number of interesting insights:

- About half (53%) of the unique license plates belong to light-duty vehicles (cars, light-commercial vehicles, motor homes) and 8% are vehicles with unidentifiable registration numbers. A minor portion of the data shows buses (0.5%) and special vehicles (0.2%, e.g. mobile machinery). Trucks make up 38% of the recorded license plates.
- Of the total number of recorded license plates, only 44% were unique, which shows that a number of vehicles regularly visit the Port area. As is shown in Figure 4.6, further analysis revealed that of the 1709 unique trucks, 44% was only counted once, 35% was counted two, three or four times, 21% was counted five times or more where one truck was counted a maximum number of 55 times in the 5 day period.

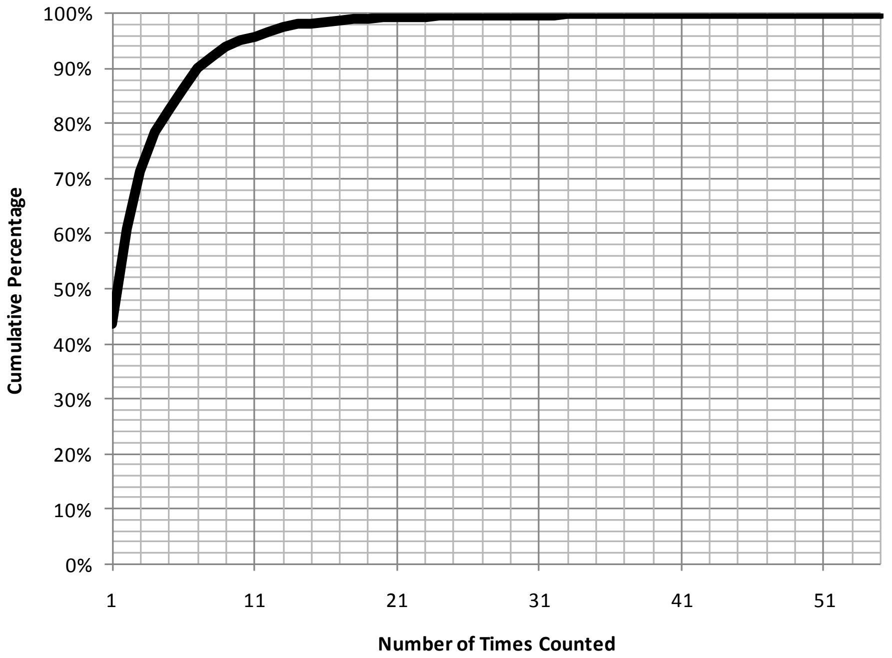


Figure 4.6: Cumulative Distribution of Unique Truck Counts at the WIM Site

Table 4.6 shows the final result of the analysis. It shows the combination of basic vehicle type and fuel type (left column) and "emission standard or 'ADR' (Australian Design Rule) categories, which reflect different levels of engine and emission control technology. ADR categories are associated with certain ranges of years of manufacture, i.e.

- pre-1990 'Uncontrolled',
- 1990-1996 'ADR 30/00',
- 1997-2002 'ADR 70/00',
- 2003-2007 'ADR 80/00', and
- 2008-2010 'ADR 80/02'.

Table 4.6: Detailed Breakdown of Fleet Composition at the WIM Site

Basic Vehicle Type and Fuel Type	Uncon-trolled	ADR 30/00	ADR 70/00	ADR 80/00	ADR 80/02	Total
MCV Diesel	0.3%	0.3%	1.1%	2.2%	0.2%	**4.1%**
MCV Petrol	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
HCV Diesel	0.7%	0.9%	3.0%	5.4%	1.0%	**10.9%**
HCV Petrol	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Semi-Trailer Diesel	8.1%	8.6%	13.3%	26.2%	1.4%	**57.6%**
Semi-Trailer Petrol	0.0%	0.1%	0.2%	0.0%	0.0%	**0.4%**
B-Double Diesel	0.6%	1.5%	4.6%	14.2%	2.6%	**23.5%**
SB-Double Diesel (Light)	0.1%	0.2%	0.7%	2.0%	0.4%	**3.4%**
SB-Double Diesel (Heavy)	0.0%	0.0%	0.0%	0.1%	0.0%	**0.1%**
Total	**9.9%**	**11.5%**	**22.9%**	**50.1%**	**5.6%**	**100.0%**

A number of observations can be made:

- The majority of trucks classify as diesel semi-trailers (58%), but there is also a substantial number of diesel B-doubles (24%), with the remainder being mainly rigid diesel trucks (15%).
- Almost all trucks use diesel fuel, with only a minor proportion using petrol. The proportion of petrol trucks is small (0.4%), with the majority being ADR 70/00 semi-trailers.
- The majority of super-B-doubles at the WIM location are light SBDs (97%) with only 3% classified as heavy SBDs. This information has been used to develop weighted emission factors for the SBD vehicle class, as will be discussed later.

Figure 4.7 shows the distribution of model years by basic vehicle class. It can be seen that the B-double and super-B-double vehicle class has the youngest fleet. This has implications for the emission inventory as will be discussed later.

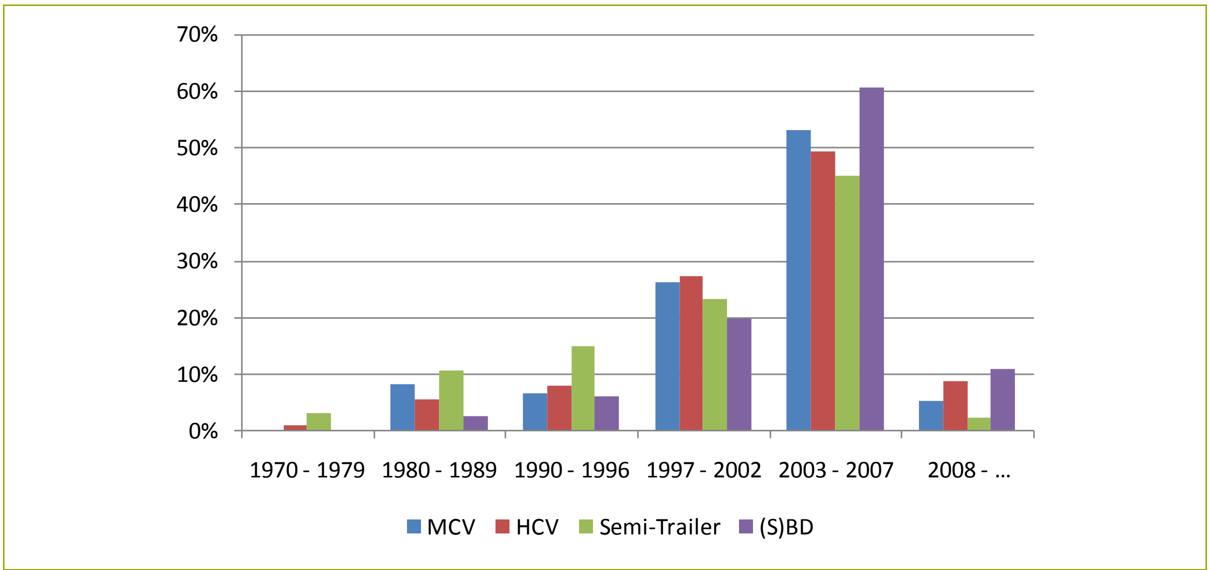


Figure 4.7: Distribution of Model Years at the WIM Site

Finally, the SD+D data also provided a breakdown of truck emission classes (by ADR category but not by vehicle type). A comparison between our original approach and the SD+D data is presented in Table 4.7. It can be seen that the distribution is quite similar, which is not surprising as both estimates are derived from DTMR registration data. Our estimate is using more recent data (June 2009) as compared with the SD+D data (2007) and is therefore more accurate. This is visible in Table 4.7 which shows that model years 2008 and beyond are not reflected in the SD+D data.

Table 4.7: Comparison of ADR Distributions (This Study and SD+D Data)

Basic Vehicle Type and Fuel Type	Original Approach	SD+D Data
pre-1990 'Uncontrolled'	8%	8%
1990-1996 'ADR 30/00'	10%	12%
1997-2002 'ADR 70/00'	23%	20%
2003-2007 'ADR 80/00'	52%	61%
2008-2010 'ADR 80/02'	7%	0%

4.2.4 VKT-Weighted Fleet Composition for the Port Area

The VKT estimation method discussed in the previous sections and the detailed analysis of WIM, DTMR and SD+D data were all combined to compute total area VKT, which amounted to about 14 million VKTs per annum, with a detailed vehicle class breakdown that is required for the emission inventory. The final results are presented in Table 4.8.

Table 4.8: Port Area Fleet Composition (VKT-weighted)

Main Vehicle Type and Fuel Type	Uncon-trolled	ADR 30/00	ADR 70/00	ADR 80/00	ADR 80/02	Total
MCV Diesel	0.63%	0.57%	2.22%	4.46%	0.45%	8.33%
MCV Petrol			0.07%			0.07%
HCV Diesel	0.77%	0.90%	3.14%	5.64%	1.00%	11.45%
HCV Petrol			0.01%			0.01%
Semi-Trailer Diesel	7.92%	8.42%	12.97%	25.57%	1.41%	56.28%
Semi-Trailer Petrol			0.37%			0.37%
B-Double Diesel	0.54%	1.28%	4.09%	12.51%	2.26%	20.67%
SB-Double Diesel	0.07%	0.17%	0.56%	1.70%	0.31%	2.81%
						100%

We emphasize that this table is the final combined outcome of the VKT work that was discussed in the previous sections. We also note that, in the absence of any further quantitative data in addition to the WIM data, the 97%-3% split of SBD into "light" and "heavy" has been used to develop weighted SBD emission factors, which are then combined with the VKT estimates for SBDs.

4.2.5 Idle Time

GPS data were provided by Chalmers and POTA for a sample of semi-trailers, B-Doubles and Super B-Doubles. These data (i.e. speed is zero km/h, engine-on) were used to compute idle time per trip or per VKT for each type of truck. To impute the idle time per trip off the island for rigid trucks, the survey undertaken by Austraffic was used (SD+D, 2010). From this survey, the ratio of the percentage of time that rigid trucks spent idling with their engines on compared to semi-trailers was found to be 80%. This is consistent with the theory that rigid trucks are expected to idle less time than semi-trailers because they do not spend as much time waiting in the container parks (queuing).

For Super B-Doubles, which are contained to the island, the idle time was expressed as idle time per VKT. Subsequently, the total number of trips off the island or total VKT were combined with this idle time information to compute total idle time. Table 4.9 shows computed idle time statistics for each basic vehicle class. A total idle time of about 387,057 hours per annum was computed for the study area.

Table 4.9: Idle Time by Basic Vehicle Class

Basic Vehicle Type	Idle Time mins/trip	Idle Time mins/VKT	Total Idle Time Hours	Total Idle Time %
MCV	21.7	-	19,725	5%
HCV	21.7	-	31,311	8%
AT	27.3	-	220,238	57%
BD	38.0	-	95,938	25%
SBD	-	3.07	19,844	5%
Total	**-**	**-**	**387,057**	**100%**

The data presented in Table 4.9 was verified against GPS data collected by SD+D. The latter indicate an average idle time for a total of 1,493 trucks, which ranged from 0.5 minutes up to 251 minutes (i.e. 4.2 hours). To minimise the bias introduced by including such extreme, and likely erroneous data, it was decided to focus on the 85^{th} and 95^{th} percentile average idle times (limits typically used in traffic engineering). These were found to be 17.8 minutes and 21.0 minutes respectively. This range is similar to the times presented in Table 1.6 for rigid trucks and semi-trailers and confirms the reasonableness of the assumed average idle times used in this analysis.

The detailed breakdown necessary for emission calculations was achieved by proportioning the total idle time for each basic vehicle class into the different subcategories (ADR, fuel type) using information presented in Table 4.6. The final results are presented in Table 4.10.

Table 4.10: Port Area Fleet Composition (Idle Time weighted)

Main Vehicle Type and Fuel Type	Uncon-trolled	ADR 30/00	ADR 70/00	ADR 80/00	ADR 80/02	Total
MCV Diesel	0.38%	0.34%	1.35%	2.71%	0.27%	5.05%
MCV Petrol	0.04%					0.04%
HCV Diesel	0.54%	0.63%	2.22%	3.98%	0.71%	8.08%
HCV Petrol	0.01%					0.01%
Semi-Trailer Diesel	7.95%	8.45%	13.03%	25.68%	1.42%	56.53%
Semi-Trailer Petrol	0.37%					0.37%
B-Double Diesel	0.65%	1.53%	4.90%	15.00%	2.71%	24.79%
SB-Double Diesel	0.13%	0.32%	1.01%	3.10%	0.56%	5.13%
						100%

4.2.6 Number of Starts

Using GPS data provided by Chalmers and POTA, the total number of starts within the study area was calculated for each vehicle class. The number of times that the semi-trailers and B-Doubles made a trip on or off the island was then counted. A ratio of starts to trips off the island was then calculated and applied to all other trucks based on their movements on and off the island. For rigid trucks the number of starts per trip off the island was imputed as being midway between one and the figure for the semi-trailers. Rigid trucks are expected to make fewer starts than semi-trailers because they do not spent as much time waiting in the container parks (queuing). For Super B-Doubles, which are contained to the island, the total number of starts was expressed as number of starts per VKT, which was found from the GPS data.

The driver surveys provided information on the split between the percentage of starts in hot and cold mode. A start was considered to be cold if the engine had been off for more than four hours. All other starts were considered hot starts. The results for each vehicle type are presented in Table 4.11. A total of about 1.5 million starts per annum was computed for the study area, of which 75% is a hot start and 25% a cold start.

Table 4.11: Number of Hot and Cold Starts by Basic Vehicle Class

Basic Vehicle Type	Number of Starts #/off-island trip	Number of Starts #/VKT	Number of Starts #	Number of Starts %	Proportion Hot/Cold Starts -
MCV	1.23	-	66,738	4%	0.50 / 0.50
HCV	1.23	-	105,941	7%	0.75 / 0.25
AT	1.54	-	745,168	47%	0.81 / 0.19
BD	3.59	-	544,596	34%	0.68 / 0.32
SBD	-	0.31	119,469	8%	0.85 / 0.15
Total	-	-	1,581,912	100%	0.75 / 0.25

It is noted that the detailed breakdown for emission calculations was achieved by proportioning the total number of cold and hot starts for each basic vehicle class into the different subcategories (ADR, fuel type) using information presented in Table 4.6. The final results are presented in Table 4.12 and Table 4.13.

Table 4.12: Port Area Fleet Composition (Cold Start weighted)

Main Vehicle Type and Fuel Type	Uncon-trolled	ADR 30/00	ADR 70/00	ADR 80/00	ADR 80/02	Total
MCV Diesel	0.64%	0.58%	2.26%	4.53%	0.46%	8.47%
MCV Petrol			0.07%			0.07%
HCV Diesel	0.45%	0.53%	1.86%	3.34%	0.59%	6.77%
HCV Petrol			0.01%			0.01%
Semi-Trailer Diesel	5.00%	5.31%	8.18%	16.14%	0.89%	35.52%
Semi-Trailer Petrol			0.23%			0.23%
B-Double Diesel	1.17%	2.73%	8.77%	26.83%	4.84%	44.34%
SB-Double Diesel	0.12%	0.28%	0.91%	2.78%	0.50%	4.59%
						100%

Table 4.13: Port Area Fleet Composition (Hot Start weighted)

Main Vehicle Type and Fuel Type	Uncon-trolled	ADR 30/00	ADR 70/00	ADR 80/00	ADR 80/02	Total
MCV Diesel	0.21%	0.19%	0.74%	1.49%	0.15%	2.78%
MCV Petrol			0.02%			0.02%
HCV Diesel	0.45%	0.52%	1.83%	3.28%	0.58%	6.66%
HCV Petrol			0.01%			0.01%
Semi-Trailer Diesel	7.11%	7.55%	11.64%	22.94%	1.27%	50.50%
Semi-Trailer Petrol			0.33%			0.33%
B-Double Diesel	0.82%	1.92%	6.16%	18.86%	3.40%	31.17%
SB-Double Diesel	0.22%	0.53%	1.69%	5.16%	0.93%	8.53%
						100%

4.2.7 Other Factors Influencing Truck Emissions

There are a number of factors that influence truck emission levels, which are accounted for in the LEI. This section discusses these factors in terms of activity input data.

4.2.7.1 Average Speed

A truck following survey was undertaken on four specified routes (refer to Appendix B for maps) within the study area in order to produce average speeds by road segment. This survey yielded results of average speeds between 57 km/h and 61km/h. There was no discernable difference between link speeds. Therefore an average speed of 60 km/h is used for the LEI.

4.2.7.2 *Road Grade*

There is only one road section within the study area that has a road grade that is greater than 0.5%, i.e. the overpass to Lucinda Drive from Port Drive. The VKT for this section of road equates to the percentages of the total VKT for the study area that are shown in Table 4.14.

Table 4.14: Proportion of VKT on Grade by Basic Vehicle Class

Basic Vehicle Class	VKT on Overpass with Significant Upgrade (> 0.5%) VKT	Total VKT VKT	Percentage of Total VKT on Overpass %
MCV	35,310	1,158,443	3.05%
HCV	10,966	1,581,370	0.69%
AT	102,813	7,816,194	1.32%
BD	36,162	2,852,246	1.27%
SBD	583	388,131	0.15%
Total	**185,834**	**13,796,384**	**1.35%**

As traffic on on-grade roads make up only a small proportion (1.35%) of overall travel within the study area, the effect of road grade on area-wide emission levels is negligible and has not been included in the computation. It is noted that the effect of road grade on emissions will be significant at the local level.

4.2.7.3 *Vehicle Loading*

To estimate the percentage of the fleet that were empty, partially loaded (half-laden) and fully loaded, data from the WIM site were used along with information on the truck classification and definitions summarized in Table 4.1. The assumed empty and fully loaded vehicle weights for the relevant *Austroads* vehicle classes are tabulated in Table 4.15, as well as 'maximum loading'. For each *Austroads* vehicle class, maximum loading was estimated by subtracting the empty vehicle mass from the maximum laden weight (both defined in Table 4.1, page 10).

Table 4.15: Vehicle Mass by Austroads Vehicle Class

Austroads Vehicle Class	Empty Vehicle Weight tonne	Fully Loaded Vehicle Weight tonne	Maximum Loading tonne
3	3.6	6.4	2.8
4	5.5	11.3	5.8
5	7.4	16.2	8.8
6	10.6	25	14.4
7	12.1	30	17.9
8	13.6	35	21.4
9	15.1	40	24.9
10	19.8	53.4	33.6

Subsequently, empty vehicle weight was subtracted from actual vehicle weight data for individual vehicles that were measured at the WIM site. If the actual vehicle loading was less than 25% of the maximum loading, the truck was considered empty. If this value was greater than 75% of the maximum load, the truck was considered full. All other trucks were counted as partially loaded. The results are shown in Table 4.16.

Table 4.16: Proportion of VKT by Vehicle Load and by Basic Vehicle Class

Basic Vehicle Class	Empty	Half-Laden	Full
MCV	0.0%	19.8%	80.2%
HCV	2.2%	17.7%	80.1%
AT	32.5%	41.6%	25.9%
BD	35.6%	24.2%	40.2%
SBD	35.6%	24.2%	40.2%

SD+D (2010) provides information on the average mass of containers by trip origin and trip destination. As these data relate to containers rather than trucks, we believe that it is not sufficiently strong to be able to impute average trucks loads or the percentage of empty, partially loaded and fully loaded trucks. For example, the SD+D data suggest that 70-75% of the containers moving around the port are empty. This reflects the high percentage of movements to and from container parks. However, we know that (on average) about 33% of all truck trips in metro Brisbane are empty. This suggests that the SD+D data is missing a significant number of loaded container (and other) truck trips on/off the island. A portion of these trips is undertaken on-island, and accordingly we believe that the SD+D data on average container loads only represents a small percentage of the total container movements.

4.2.7.4 Retrofit Technology

Driver surveys were used to examine the use of retrofit emission control technology in the truck fleet operating in the Port area. During the interviews, drivers were asked to give details of any after-market emission reduction or fuel-efficiency retrofits that had been done to their trucks. Of the 204 drivers surveyed, three drivers mentioned a retro-fit. The answers were not sufficiently clear (i.e. two drivers answered "ad blue" and one answered "bigger exa"). Importantly, the model year of the truck was not provided. This information is required to identify the correct ADR category.

The data indicate that the majority of trucks (> 98.5%) are not retro-fitted. It also appears that two of the three positive replies refer to the use of SCR technology (which uses the aqueous urea solution Ad Blue). It is noted that this technology is already reflected in the emission factors for the ADR 80/02 vehicle category, which account for 5% of VKT weighted travel in the area.

4.2.7.5 Alternative Fuels

No information on the use of alternative fuels (e.g. biodiesel, ULSD) could be found in either the DTMR data or the driver survey data. Hence, no activity data could be computed for these fuels and their use in the Port area has been assumed to be non-existent or insignificant.

4.2.8 Summary of Road Traffic Activity Data

Table 4.17 presents the total annual VKT, total idle time and total number of starts for the 2007/08 year within the Port of Brisbane Study area.

Table 4.17: Truck Activity Data - Final Results

Basic Vehicle Class	VKT		Idle Time		Hot Starts		Cold Starts	
	Million VKT	%	Hour	%	1000 Starts	%	1000 Starts	%
MCV	1.16	8%	329	5%	33	3%	33	9%
HCV	1.58	11%	522	8%	79	7%	26	7%
Semi	7.82	57%	3,671	57%	605	51%	140	36%
BD	2.85	21%	1,599	25%	371	31%	173	44%
SBD	0.39	3%	331	5%	102	9%	18	5%
Total	**13.80**	**100%**	**6,451**	**100%**	**1,191**	**100%**	**391**	**100%**

4.2.9 Comparison with Previous Work (Sensitivity of the Results)

Table 4.18 compares estimates of traffic activity of Phase 1 of this project (PAEHolmes, 2009) – denoted as "initial" results – and the more refined final results presented in this report. This information provides some insight in the sensitivity of the activity estimates in terms of the assumptions.

Table 4.18: Comparison of Initial and Final Estimates of Traffic Activity

Traffic Activity Type	Initial	Final	Difference
VKT (million)	12.45	13.80	11%
Idle Time (hours)	40,968	387,057	845%
Number of Hot Starts (1000)	410	1,191	191%
Number of Cold Starts (1000)	410	391	-5%
Total Number of Starts (1000)	819	1,582	93%

It can be seen that the total annual VKT estimated from Phase 2 is 11% more than the initial estimate. This is mainly due to the more sophisticated method used in the final assessment. This indicates that the sensitivity of total travel to the assumptions is not large. The other traffic activity parameters (idle, starts) are substantially more sensitive and experience a significant change in predicted values. The reason for the large increase in total idle time (a factor of about 9) is that initially an average idle time of 90 seconds per trip off the island was assumed, while we were able to obtain a more accurate figures on idle times from the GPS data for the final work. Similarly, we were able to obtain more accurate estimates of the number of starts per trip off the island or on the island and the distribution between hot and cold starts for each basic vehicle type.

4.3 Emission Factors

Large errors can occur when overseas emission algorithms for on-road traffic (e.g. MOBILE, COPERT) are directly used in Australia (e.g. Smit, 2008; Smit & McBroom, 2009). This is due to several factors including differences in fleet characteristics, engine calibration practices and exhaust emission standards. As a consequence, truck emission factors used for this project are based on Australian test data to the extent these are available. The current NPI manual for motor vehicle emissions (EA, 2000) does not adequately reflect Australian conditions and is based on emissions data that are seriously outdated and, importantly, for trucks are based on an overseas model (MOBILE 5a) – that has been updated itself into MOBILE 6.

4.3.1 Emission Factor Database

PAEHolmes' emission factor database has been used as the basis for truck emission factors. This emission model was originally developed in 2002 for Queensland EPA for the South-East Queensland Emission Inventory for Motor Vehicles (Pekol *et al*., 2003), but has been updated and expanded in 2008 to include the latest Australian vehicle emissions test data and to incorporate new information that has been published overseas. The model is now based on Australian test data consisting of a database with almost 2000 vehicle emission tests, based in part on a driving cycle called the CUEDC-D[b].

Importantly, these emission factors are based on measured Australian driving behaviour and take into account differences in driving behaviour between trucks with different configurations and power-to-mass ratios. The traffic emissions model consists of a **fleet composition model**[c] and an **average speed emission model**. The average speed model computes basic hot running emission factors[d] (expressed as g/km), which are corrected for in-use deterioration (ageing), average speed, road gradient, air-conditioning use, fuel quality (e.g. sulphur content) and ambient temperature. It includes emission factors for start (gram/start)[e], idling (gram/hour)[f], evaporative emissions[g] and non-exhaust particulate emissions[h], which are corrected for in-use deterioration (ageing), fuel quality and ambient temperature.

---

[b] The CUEDC-D or Composite Urban Emission Drive Cycle - Diesel was developed for four types of road and traffic flow ("congested", "minor road", "arterial", "highway") and was constructed from on-road driving pattern data in Sydney collected by instrumented vehicles.

[c] A fleet composition models takes into account vehicle sales, scrappage rates, growth rates and vehicle activity (e.g. mean annual VKT), which are a function of vehicle age, calendar year or (vehicle) model year. These proportions or "weighting factors" are then used to compute composite emission factors reflecting a less detailed vehicle classification scheme that matches the available traffic input data.

[d] Hot running emissions: exhaust emissions that occur under "hot stabilized" conditions, which means that the engine and the emission control system (e.g. catalytic converter) have reached their typical operating temperatures.

[e] Start emissions: additional exhaust emissions that occur because engines and catalysts are not (fully) warmed up and operate in a non-optimal manner. The difference between emission rates at normal operating temperature and those during the warming up period are generally described as "excess" emissions (grams), and can be quite significant – in particular for light-duty vehicles - given the typically low emission levels of vehicles with warmed up engines and emission control systems.

[f] Idle emissions: exhaust emissions that occur when the vehicle is stationary and engine is on.

[g] As well as being emitted from the tailpipe of motor vehicles, hydrocarbon compounds (HCs) are also released to the atmosphere in running or parked vehicles through the evaporation of fuel via leaks in fuel filler caps, hot engine parts or failures in a vehicle's on-board vapour recovery systems. These emissions are not relevant for diesel, LPG and CNG trucks and are excluded from this project.

One important aspect of truck emission factors is the level of breakdown into vehicle classes. The (corrected) emission factors are available for 39 half-laden heavy commercial vehicle (HCV) classes, which are classified using the following factors:

- Vehicle type:
  - medium rigid truck - medium commercial vehicle (MCV);
  - heavy rigid truck - heavy commercial vehicle (HCV);
  - semi-trailer (ST); and
  - bus.
- Fuel type (diesel, CNG, LPG, petrol).
- Year of manufacture/ADR category (reflecting vehicle and technology classes).

This high level of detail is needed for this project as it aims to reflect local traffic composition. However, not all relevant aspects are reflected in those emission factors, namely:

- Port-specific vehicle configurations (e.g. B-doubles, super-B-doubles);
- Vehicle loading; and
- Specific fuels and/or retrofit devices.

Specific emission factors have been developed for these aspects and they are discussed in sections 4.3.2, 4.3.3 and 4.3.4. An overview of all emission factors used in this project can be found in a separate spreadsheet called "Truck emission factors PBC LEI 2007-2008.xls". This spreadsheet shows emission factors for 630 vehicle classes, 16 pollutants and 4 types of emission (hot running, idle, cold start, hot start).

4.3.2 Port-Specific Vehicle Configurations

Emission factors for MCVs, HCVs and semi-trailers were available from PAEHolmes' emission factor database (refer to the previous section). Specific emission factors for B-doubles and super-B-doubles have been developed for this project.

We could not find any suitable empirical emissions data for the heavier B-doubles and super-B-doubles. We have therefore used an energy-based approach to develop emission factors for these heavier vehicle types. This approach considers that, apart from aerodynamic drag, virtually all required engine power is directly proportional to vehicle mass for any given on-road driving pattern. This is particularly the case for fuel consumption (and thus CO_2). Another consideration is that all heavy-duty vehicle engines are certified by measuring their emissions on an energy basis – usually grams of pollutant per kilowatt hour (g/kWh) when "driven" on a dynamometer test bed to a pre-defined torque-speed profile. This is in contrast with light-duty vehicles which are certified using measured emissions over an actual driving cycle (speed-time profile), which are normalised per unit distance (i.e. g/km).

Given these factors, it is reasonable to calculate approximate emission factors for heavier vehicles with larger engines based on the emissions of a similar technology, but lighter smaller-engine vehicle, using the ratio of their on-road mass.

[h] These emissions are due to wear and tear of e.g. tyres, brakes, etc. and given the ongoing reduction in exhaust emissions are of growing importance.

For example, let's take a case where we want to estimate emissions for a 55 tonne B-double rig, but we only have data for a similar technology 40 tonne articulated vehicle. If typical on road particle (PM) emissions for the articulated rig are, say, 0.35 g/km, then we can estimate the B-double emissions, in similar traffic conditions, to be around 0.35 x 55/40 = 0.48 g/km. This approach was used for the development of emission factors for B-doubles and super-B-doubles, and it resulted in the following scale factors:

- B-Double: multiply emission factors for semi-trailers with **1.5** ; and
- Super B-Double: multiply emission factors for semi-trailers with **0.9**.

The scale factor for super B-doubles is less than 1 because this category includes both light and heavy super B-doubles, which make up about 97% and 3% of the B-double fleet respectively, as was discussed in the previous sections. As a consequence, the half laden weight of a super B-double is 22.0 tonne, which is lighter than the mean value for semi-trailers (25.9 tonne, refer to Table 4.1).

A limited validation of this approach was conducted by comparing the predicted emission factors with test results for 2 trucks (refer to Appendix A). The comparison shows that the scaling approach works well for vehicles with similar engine and emission control technology. However, it is recommended that the emission factors are updated when empirical emissions data becomes available for these vehicle categories.

4.3.3 Vehicle Loading

A fully loaded truck will require more energy to travel from A to B than an empty or half-laden vehicle. As a consequence, emissions are generally higher when vehicle loading increases. The actual effects of vehicle loading, however, depend on vehicle type and technology, driving behaviour, road grade and pollutant/GHG considered. Moreover, there are interactions. For instance, a truck is driven in a different fashion when an empty and fully loaded vehicle are compared, e.g. in terms of accelerations and gear shift behaviour.

Information on the quantitative effects of vehicle loading on emissions is very limited. The only credible source of information we found is the European ARTEMIS traffic emission model (INFRAS, 2007). We have extracted "load correction factors" from this model to develop additional emission factors for "empty" and "fully loaded" trucks. These correction factors have only be used to correct hot running emission factors. Idling emission factors have not been corrected as energy demand for idling is not affected by vehicle load. Start emissions are affected by vehicle loading, but start emission factors were not corrected due to a lack of information on the actual direction and magnitude of the effect[i].

[i] Start emissions are a function of several factors including warm-up time, which in turn depends on power demand. A higher power demand results in a faster warm up of the engine and catalyst system, which encourages early light-off. As a consequence, start emissions can actually be lower when vehicle loading increases, but there are no empirical data available for trucks to quantify this effect.

4.3.4 Specific Fuels and/or Retrofit Devices

Use of alternative fuels will change the emissions profile of on-road trucks. Although they have not been used in the 2007/08 emission inventory (as there is yet no significant penetration of alternative fuels in the on-road fleet in the Port area), we have developed emission factors for two alternative fuels, i.e. biodiesel (100%) and ultra-low sulphur diesel (ULSD). Biodiesel is a generic name for fuels obtained by etherification of vegetable oils and animal fats. Biodiesel can be produced from a variety of feedstock's including rapeseed oil, soybean oil, sunflower oil and palm oil. Although literature indicates that biodiesel generally provides significant emission benefits with respect to CO, HC and particulates, but (slightly) higher NO_x, an international review (Smokers and Smit, 2004) showed that these conclusions are not always supported by experimental data. We have used information from an Australian study (Beer *et al*., 2001) to develop correction factors for CO, HC, NO_x and PM.

For GHGs (i.e. CO_2-e) and SO_2, we have used the input data presented in Table 3.1. It is noted that fuel consumption has been estimated by considering that the same amount of energy is required to propel a vehicle, but taking into account the different LHVs (Table 3.1) for diesel and biodiesel. CO_2 (exhaust), CH_4 and N_2O emission factors have not been corrected due to a lack of information. No correction factors were developed for retrofit devices as driver surveys showed that these devices are not (yet) used in the Port area to a significant extent.

4.4 Truck Emission Inventory

The activity data and the emission factor database were combined to develop the truck emission inventory using the following formulae:

$$EMIS = EF_{g/veh.km} \times VKT \div 1000$$ (hot running emissions)

$$EMIS = EF_{g/veh.start} \times No\_Starts \div 1000$$ (start emissions, hot/cold)

$$EMIS = EF_{g/s} \times Idle\_Time \div 1000$$ (idle emissions)

where EMIS represents total area emissions in kg/year and for each vehicle class:

- EFg/veh.km represents the hot running emission factor (g/veh.km),
- VKT represents total vehicle kilometers travelled (veh.km),
- EFg/veh.start represents the start emission factor (g/veh.start), either hot or cold,
- No_Starts represents total number of starts (veh.start), either hot or cold,
- EFg/s represents the idle emission factor (g/s), and
- Idle_Time represents total idle time (s).

The results are presented in Table 4.19, broken down by type of emission.

Table 4.19: Total Emissions from Trucks by Operating Mode

Pollutant	Hot Running kg/year	Idling kg/year	Hot Start kg/year	Cold Start kg/year	Total kg/year
Air Pollutants					
CO	30,290	12,352	65	991	43,699
THC	6,021	4,203	9	312	10,546
NO_x	196,093	22,667	4	5,495	224,260
SO_2	636	80	0	24	740
$PM_{10,exhaust}$	2,188	234	0	64	2,486
$PM_{2.5,exhaust}$	2,081	223	0	61	2,365
$PM_{10,non-exhaust}$	1,629	0	0	0	1,629
$PM_{2.5,non-exhaust}$	900	0	0	0	900
$PM_{10,total}$	3,817	234	0	64	4,115
$PM_{2.5,total}$	2,981	223	0	61	3,264
Greenhouse Gases					
CO_2	20,085,527	2,502,941	0	754,030	23,342,497
CH_4	702	479	1	36	1,218
N_2O	623	71	0	20	714
CO_2-e	20,629,906	2,600,335	0	774,619	24,004,861
Fuel Use					
Fuel Consumption	6,351,543	800,525	0	238,516	7,390,584

The following observations follow from Table 4.19:

- Emissions are mainly hot running emissions; 60-100% depending on the pollutant.
- Idle emissions make up a significant portion of total truck emissions; 0-40% depending on the pollutant. Idling is particularly relevant for THC and methane (both 40%) and CO (30%).
- Hot start emissions are negligible and cold start emissions only make up a very small portion of total emissions; 0-3% depending on the pollutant.

The results are presented in Table 4.20, broken down by type of fuel.

Table 4.20: Total Emissions from Trucks by Fuel Type

Pollutant	Diesel kg/year	LPG kg/year	CNG kg/year	ULSD kg/year	Biodiesel kg/year	Petrol kg/year
Air Pollutants						
CO	37,606	0	0	0	0	6,093
THC	9,741	0	0	0	0	804
NO_x	223,931	0	0	0	0	329
SO_2	737	0	0	0	0	3
$PM_{10,exhaust}$	2,486	0	0	0	0	0
$PM_{2.5,exhaust}$	2,364	0	0	0	0	0
$PM_{10,non-exhaust}$	1,622	0	0	0	0	7
$PM_{2.5,non-exhaust}$	896	0	0	0	0	4
$PM_{10,total}$	4,108	0	0	0	0	7
$PM_{2.5,total}$	3,260	0	0	0	0	4
Greenhouse Gases						
CO_2	23,292,802	0	0	0	0	49,695
CH_4	1,164	0	0	0	0	54
N_2O	712	0	0	0	0	2
CO_2-e	23,953,678	0	0	0	0	51,183
Fuel Use						
Fuel Consumption	7,374,888	0	0	0	0	15,697

The following observations follow from Table 4.20:

- The majority of emissions are due to combustion of diesel fuel in trucks; 85%-100% depending on the pollutant.
- LPG, CNG, ULSD and biodiesel are not relevant for the emission inventory.
- Petrol is generally negligible with respect to total fuel consumption and emissions (< 0.5%), except for carbon monoxide, methane and total hydrocarbons where it can make up 14%, 4% and 8% of total truck emissions respectively.

The results are presented in Table 4.21, broken down by basic vehicle type.

Table 4.21: Total Emissions from Trucks by Basic Vehicle Type

Pollutant	MCV kg/year	HCV kg/year	ST kg/year	BD kg/year	SBD kg/year
Air Pollutants					
CO	2,827	2,132	30,138	7,877	725
THC	649	700	6,166	2,768	263
NO_x	6,050	15,658	135,723	61,736	5,092
SO_2	31	59	400	230	19
$PM_{10,exhaust}$	208	243	1,523	473	39
$PM_{2.5,exhaust}$	198	231	1,449	450	37
$PM_{10,non-exhaust}$	119	178	883	400	48
$PM_{2.5,non-exhaust}$	61	94	487	231	27
$PM_{10,total}$	327	421	2,406	873	87
$PM_{2.5,total}$	259	325	1,936	681	64
Greenhouse Gases					
CO_2	963,541	1,880,129	12,607,029	7,291,215	600,583
CH_4	84	110	676	318	30
N_2O	28	56	391	221	18
CO_2-e	992,159	1,931,537	12,973,819	7,490,040	617,305
Fuel Use					
Fuel Consumption	305,469	594,710	3,993,707	2,306,597	190,102

The following observations follow from Table 4.21:

- Semi-trailers contribute the largest portion to the truck emission inventory; 55%-70% depending on the pollutant.
- B-Doubles contribute a substantial portion to the truck emission inventory; 20%-30% depending on the pollutant.
- Rigid Trucks (MCVs, HCVs) contribute a significant portion to the truck emission inventory; 10%-20% depending on the pollutant.
- Super B-Doubles contribute a small portion to the truck emission inventory; 2%-3% depending on the pollutant.

Table 4.22 also shows the mean emission factors by basic vehicle type that have been computed by dividing total hot running emissions with total VKT.

Table 4.22: Weighted Hot Running Emission Factors by Basic Vehicle Type

Pollutant	MCV g/km	HCV g/km	ST g/km	BD g/km	SBD g/km
Air Pollutants					
CO	1.86	0.98	2.74	1.68	0.98
THC	0.38	0.28	0.46	0.52	0.30
NO_x	4.64	8.76	15.41	18.33	10.65
SO_2	0.02	0.03	0.04	0.07	0.04
$PM_{10,exhaust}$	0.16	0.14	0.17	0.14	0.08
$PM_{2.5,exhaust}$	0.15	0.13	0.16	0.13	0.08
$PM_{10,non-exhaust}$	0.10	0.11	0.11	0.14	0.12
$PM_{2.5,non-exhaust}$	0.05	0.06	0.06	0.08	0.07
$PM_{10,total}$	0.27	0.25	0.29	0.28	0.21
$PM_{2.5,total}$	0.21	0.19	0.23	0.21	0.15
Greenhouse Gases					
CO_2	722	1,077	1,406	2,129	1,237
CH_4	0.05	0.04	0.05	0.06	0.03
N_2O	0.02	0.03	0.04	0.07	0.04
CO_2-e	743	1,106	1,445	2,185	1,269
Fuel Use					
Fuel Consumption	229	340	445	673	391

Figure 4.8 graphically shows the contribution of each vehicle class, defined as 26 combinations of vehicle and fuel type, in more detail.

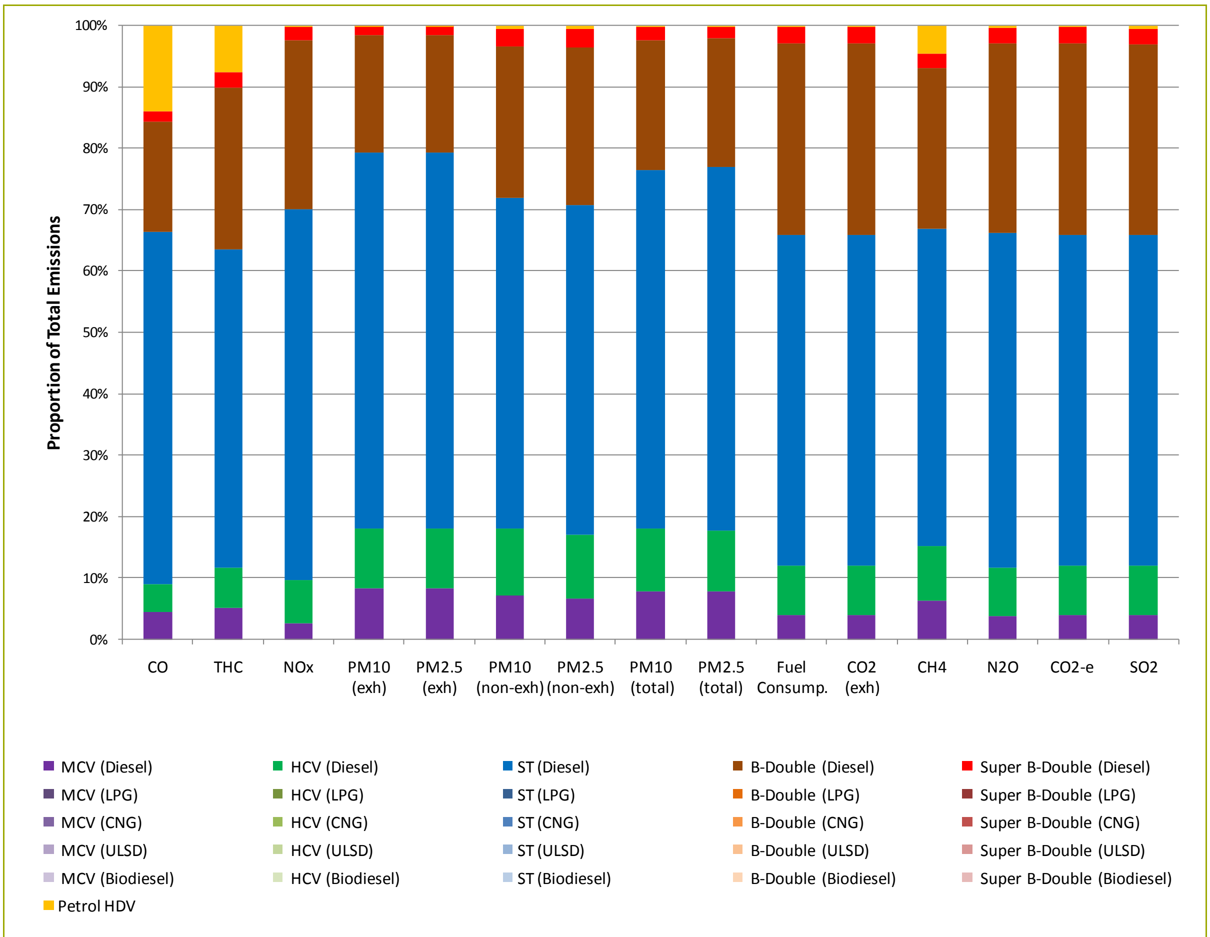


Figure 4.8: Contribution of Different Vehicle Classes to Total Truck Emissions

The following observations follow from Figure 4.8:

- Diesel semi-trailers (blue) are the most important vehicle type for all pollutants (50-60% of total truck emissions).
- Diesel B-Doubles are an important vehicle type with contributions to total truck emissions in the order of 20-30% depending on the pollutant.
- B-Doubles use about one-third of total fuel, but have a less than proportionate contribution to total emission levels. Further analysis of this interesting result revealed that this is because B-Doubles have a younger fleet composition with better emission control, as compared with semi-trailers. For instance about 60% and 10% of B-Doubles classify as ADR80/00 and ADR80/02 vehicles respectively, which compares to 45% and 3% for semi-trailers, as was shown in Table 4.8.
- Diesel rigid trucks (MCVs, purple; HCVs, green) are a relevant vehicle type with contributions to total truck emissions in the order of 10-20% depending on the pollutant.
- Diesel Super-B-Doubles only make up a minor portion of total emissions (2-3%).
- Petrol trucks generally make a negligible contribution to total emissions (< 0.5%), which is in line with their low proportion of vehicle activity, except for CO, methane and THC where it can make up 14%, 4% and 8% of total truck emissions respectively.
- Trucks using other fuels (ULSD, biodiesel, CNG, LPG) make no contribution to total emissions, as there is no evidence of traffic activity data for these fuel types.

Table 4.23 compares the initial and final results for total truck emissions. It can be seen that truck fuel consumption and associated emissions (CO_2, CO_2-e, SO_2) have increased with about 60%. This is not only due to the increase in vehicle activity, but also due to the use of the power-based scale factor for B-doubles, which will increase emissions from this category with 50%. However, not all emissions have increased as much. This is the case for several pollutants (CO, HC, PM, CH_4). The main reason for this is the increase in average speed to 60 km/h, which was initially assumed to be 40 km/h. Emission factors for CO, HC, PM and CH_4 (g/veh.km) are sensitive to speed and have decreased substantially (typically 20-35%) because of this change in speed, whereas emission factors for NO_x are stable and typically increase with a few percent. This explains the substantial increase in NO_x emissions from trucks (about 90%).

Table 4.23: Total Emissions from Trucks

Pollutant	Total Truck Emissions Initial LEI kg/year	Total Truck Emissions Final LEI kg/year	Difference %
Air Pollutants			
CO	37,596	43,699	16%
THC	8,166	10,546	29%
NO_x	119,769	224,260	87%
SO_2	459	740	61%
$PM_{10,exhaust}$	2,128	2,486	17%
$PM_{2.5,exhaust}$	2,025	2,365	17%
$PM_{10,non-exhaust}$	1,586	1,629	3%
$PM_{2.5,non-exhaust}$	833	900	8%
$PM_{10,total}$	3,714	4,115	11%
$PM_{2.5,total}$	2,858	3,264	14%
Greenhouse Gases			
CO_2	14,337,552	23,342,497	63%
CH_4	906	1,218	34%
N_2O	447	714	60%
CO_2-e	14,745,699	24,004,861	63%
Fuel Use			
Fuel Consumption	4,541,322	7,390,584	63%

5 RAIL

In consideration of overseas studies (e.g. Starcrest, 2007), rail emissions are expected to generally be a minor source of emissions in the LEI. Rail emissions are a function of:

- "rail activity", which involves the total hours of operation, the amount of time spent idling and operation in different "notches"; and
- factors that influence fuel consumption and emission rates, such as type of locomotive and the way it is driven.

This section discusses the rail systems that operate in the Port area, including the types of activities performed, the equipment used, and the methods of estimating emissions. Rail operations are typically described in terms of two different types of operation, line haul and shunting. Line haul refers to the movement of cargo (container, coal, grain) over long distances and occurs within the Port as the initiation or termination of a line haul trip. Shunting refers to the sorting, assembling and disassembling of trains and short distance hauling of rail cargo within the Port area.

Locomotives used for line haul operations are typically larger and more powerful engines as compared to those used in shunting operations. Figure 5.1, Figure 5.2, Figure 5.3 show typical QR locomotives that are currently in service.

Figure 5.1: A 1150 Hp, 8 Cylinder 2-Stroke Diesel Shunting Locomotive

Figure 5.2: A 2,300 Hp 12 Cylinder 2-Stroke Diesel Turbo Locomotive

Figure 5.3: A 3,000 Hp 12 Cylinder 4-Stroke Diesel Turbo Locomotive

This section will first discuss the Port area locomotive classification and rail activity (section 5.1), subsequently a discussion of emission factors (section 5.2) and finally present the results of the rail emission inventory (section 5.3).

5.1 Activity Data

Rail activity data for the 2007/2008 base year were provided by Queensland Rail (QR). QR (logistics office and internal discussions with experienced drivers in charge) provided us with data on the typical number of trains that operate in the study area (trains per year), train configuration (number of locomotives per train) and total time each train typically spends in the study area (hours per train). This information was used to compute the total number of locomotive hours per year, which is categorized by "process" (coal, grain, etc.). Table 5.1 (first three columns) presents an overview of these data.

Table 5.1: Overview of Activity Data for Rail

Process	Number of Locomotives [*] $year^{-1}$	Total Locomotive Time in Area hr/year	Configuration and Rated Engine Power Hp	Mean Fuel Consump-tion Rate l/hr	Total Fuel Consump-tion l/year
Coal	7,072 [40]	14,144	2 x 2300	59.8	846,236
Grain	1,248 [40]	2,496	2 x 2300	59.8	149,336
Container - SW general	312 [30]	780	2 x 2300	64.1	49,998
Container - SW Cotton	264 [40]	660	2 x 2300	64.1	42,306
Container - NCL Biloela	216 [30]	540	2 x 2300	64.1	34,614
Container - Rockhampton	260 [24]	650	1 x 3000	92.1	59,872
Container - Townsville	354 [40]	884	1 x 2300/3000	78.1	69,045
Shunting	260 [-]	260	1 x 1150	24.6	6,383
TOTAL	**9,986**	**20,414**	**-**	**-**	**1,257,789**

* Within square brackets: typical number of wagons per train.

QR also provided us with measured fuel consumption rates (obtained with the on-board load box) in the various operating modes on the engines types used in QR locomotives. These data are presented in Table 5.2.

Table 5.2: Measured Fuel Consumption Rates by Engine Type (Litres/Hour)

Notch	1150 Hp, 8 Cylinder 2-Stroke	2300 Hp, 12 Cylinder 2-Stroke, Turbo	3000 Hp, 12 Cylinder 4-Stroke, Turbo
Idle	3.6	7.0	9.9
1	21.1	18.5	32.3
2	31.2	57.3	74.5
3	55.5	100.3	157.1
4	81.9	149.7	228.3
5	113.2	220.2	317.3
6	146.6	286.2	403.3
7	180.8	378.7	495.2
8	223.4	435.1	613.6

Typical locomotive operation (expressed as percentage of time in "notch") was obtained from discussions with experienced train drivers. It was considered that bulk trains (coal/grain) typically spent approximately 2 hours in the study area of which about two thirds is spent unloading in "Notch 2" operation mode. The container trains operate differently where the majority of trains come in loaded and depart with empty containers. Locomotives are shut down during loading and unloading and then spent up to two hours idling (including departure test and possibly wagon check) at the BMT. After this they depart in higher notch mode. The results are shown in Table 5.3.

Table 5.3: Time-in-Notch Operation by Main Process

Notch	Shunting	Coal/Grain	Containers
Idle	67%	5%	80%
1	6%	10%	0%
2	8%	70%	0%
3	7%	10%	0%
4	5%	5%	10%
5	3%	0%	0%
6	2%	0%	0%
7	1%	0%	0%
8	1%	0%	10%
Total	**100%**	**100%**	**100%**

Table 5.2 and Table 5.3 were then combined to compute weighted average fuel consumption factors for the relevant engine type / main process combinations. The results are represented in Table 5.4. These fuel consumption rates were used to compute total fuel consumption for each process, as presented in the last two columns of Table 5.1.

Table 5.4: Mean Fuel Consumption by Locomotive Type

Locomotive Type	Mean Weighted Fuel Consumption Rate (Liters/Hour)
Shunting, 1150 Hp, 8 Cylinder 2-Stroke	24.6
Coal/Grain, 2300 Hp, 12 Cylinder 2-Stroke, Turbo	59.8
Containers, 2300 Hp, 12 Cylinder 2-Stroke, Turbo	64.1
Containers, 3000 Hp, 12 Cylinder 4-Stroke, Turbo	92.1

5.2 Emission Factors

Fuel-based emission factors for uncontrolled diesel locomotives were re-computed using the original data source (EEA, 2007) used by the NPI manual for Railway Yard Operations (DEWHA, 2008) to reflect different values for diesel fuel density and lower heating value (LHV) and to enable the use of engine power-specific emission rates in the LEI. The following formula was used to compute fuel-based emission factors for this project:

$$EF_{g/l} = EF_{g/kWh} \times LHV \times D \times \varepsilon_T \times CF$$

where $EF_{g/l}$ represents the emission factor (g/l fuel), $EF_{g/kWh}$ represents the emission factor (g/kWh), which is a function of rated engine power and is sourced from EEA (2007), the recently updated standard European emission inventory guide, LHV is the lower heating value (MJ/kg fuel, 43.0 for diesel), D is the fuel density (0.83 kg/l for diesel), ε_T represents the thermal engine efficiency, which is a function of rated engine power and CF is a conversion factor (0.28 kWh/MJ). The results are presented in Table 5.5 (locomotives > 130 kW).

Table 5.5: Fuel-Based Emission Factors for Uncontrolled Diesel Locomotives

Pollutant	Emission Factor g/l fuel
CO	9.80
THC	4.25
NO_x	47.06
SO_2	0.08
$PM_{10,exhaust}$	3.51
$PM_{2.5,exhaust}$	3.37
$PM_{10,non-exhaust}$	NA
$PM_{2.5,non-exhaust}$	NA
$PM_{10,total}$	3.51
$PM_{2.5,total}$	3.37
CO_2	2604
CH_4	0.16
N_2O	1.14
CO_2-e	2698
Fuel Consumption	830

QR confirmed that commercially available low sulphur fuel (50 ppm-m S) is used in the locomotives, which is reflected in the fuel-based SO_2 emission factor in Table 5.5. In addition, it was confirmed that no after-treatment technologies are currently in use (e.g. SCR, particulate filters) and that locomotives are re-engined according to original specifications. This validates the use of fuel-based emission factors for uncontrolled engines.

5.3 Rail Emission Inventory

The activity data provided by QR (Table 5.1) and the emission factors presented in 5.2 were combined to develop the rail emission inventory using the following formula:

$$EMIS = EF_{g/l} \times FC \div 1000$$

where EMIS represents total area emissions in kg/year, $EF_{g/l}$ represents the emission factor (g/l fuel - Table 5.5) and FC represents total fuel consumption (l/year - Table 5.1, last column). The results are presented in Table 5.6.

Table 5.6: Total Emissions from Diesel Locomotives

Pollutant	Total Rail Emissions Initial LEI kg/year	Total Rail Emissions Final LEI kg/year	Difference %
Air Pollutants			
CO	11,636	12,330	+6%
THC	5,042	5,343	+6%
NO_x	55,852	59,185	+6%
SO_2	98	104	+6%
$PM_{10,exhaust}$	4,164	4,413	+6%
$PM_{2.5,exhaust}$	3,995	4,233	+6%
$PM_{10,non-exhaust}$	NA	NA	NA
$PM_{2.5,non-exhaust}$	NA	NA	NA
$PM_{10,total}$	4,164	4,413	+6%
$PM_{2.5,total}$	3,995	4,233	+6%
Greenhouse Gases			
CO_2	3,091,060	3,275,534	+6%
CH_4	194	206	+6%
N_2O	1,358	1,439	+6%
CO_2-e	3,202,561	3,393,690	+6%
Fuel Use			
Fuel Consumption	985,170	1,043,964	+6%

It also compares the final LEI figures to the results from Phase 1 (initial). It can be seen that rail fuel consumption and emissions have increased with 6% across the board. Differences are uniform as emission factors (g/l) have not changed in Phase 2, only mean fuel consumption rates.

6 CARGO HANDLING EQUIPMENT (CHE)

Cargo handling equipment (CHE) is utilised at port facilities to move cargo containers, move products within the containers, and other various activities. There are several industries located at the Port of Brisbane (PoB) that use a wide variety of CHE. Figure 6.1 includes pictures of typically used CHE at PoB.

The PoB CHE emissions were estimated for the 2007/2008 financial year. This section outlines the methods of establishing emission factors as well as the information about the CHE activity data reported from the facilities located at the PoB. Section 6.1 discusses the industries located on PoB and the reported CHE activity on these sites. Section 6.2 discusses the emission factors used for analysis and section 6.3 presents the results of the CHE emission inventory.

Forklift – Small

Forklift - Large

Crane

Compressor/Generator

Figure 6.1: Types of CHE used at PoB industries

Empty/Full Handler

End Loader

Reach Stacker

Skid-Steer Loader

Terminal Tractor

Dozer

Figure 6.1: Types of CHE used at PoB

6.1 Activity Data

CHE activity data was requested by the Port of Brisbane from all operating facilities within the port in the form of a CHE survey, shown in Appendix C. Some companies completed the survey and others reported partially completed surveys, while some facilities failed to report. The survey requested the following data[j]:

- equipment type and quantity;
- chassis make and model,
- chassis model year;
- engine make and model
- engine model year
- engine rated power (HP or kW);
- fuel used and sulphur content;
- operating hours for 2007/2008;
- cumulative engine hours; and
- total fuel used in 2007/2008.

Industry CHE activity inquiries were made with site visits and phone/email conversations. In addition, alternative sources of information were also utilised for further completion of Port of Brisbane CHE activity data. Table 6.1 lists the industry groups and companies located within the Port of Brisbane and the quality of the corresponding CHE activity data.

[j] Engine model year and engine rated power were used to determine the appropriate NONROAD emission factors for each piece of CHE. The year 2000 emerged as a typical average engine model year and this value was used in the absence of engine model year information.

Table 6.1: Companies Considered in the CHE Emission Inventory

Industry Group	Company	CHE Data Detail [a]	CHE Emissions Importance
Stevedores	DP World	VH	Very Important
Stevedores	Patrick	H	Very Important
Stevedores	AAT	M	Important
Container Parks & Dep.	Chalmers	H	Important
Container Parks & Dep.	P&O	H	Important
Container Parks & Dep.	Patrick Port Logistics	L	Important
Bulk Commodities	Graincorp	VH	Minor
Bulk Commodities	Queensland Commodity Exports	L	Minor
Bulk Commodities	Sunstate Cement	M	Minor
Bulk Commodities	Caltex	M	Minor
Bulk Commodities	Queensland Bulk Handling	M	Minor
Service Industries	Australian Customs	VH	Insignificant
Service Industries	Dredco	VH	Insignificant
Service Industries	Hawkins Transport	VH	Insignificant
Service Industries	QLD Water Police	L	Insignificant
Service Industries	Baulderstone	L	Insignificant
Service Industries	Australian Terminal Service	VH	Insignificant
PBC Facilities	BMT	VH	Minor
Warehouses	Tzaneros West	L	Insignificant
Warehouses	Carter Hold Harvey and Linfox	L	Insignificant
Warehouses	Tzaneros and Port Gate Logistics	L	Insignificant
Warehouses	ACFS	M	Insignificant
Warehouses	Toll Chemicals	L	Insignificant
Warehouses	Steel Force	L	Insignificant
Warehouses	IPS Logistics	H	Insignificant

a. HV – Very High, H – High, M – Medium, L -Low

Further information concerning the quality of the CHE activity data and any assumption made for the Port of Brisbane companies are discussed below.

6.1.1 Stevedores

6.1.1.1 DP World

The survey received was complete.

6.1.1.2 Patrick Terminal

The Patrick Terminal port operations total fuel use was reported to PAEHolmes by Craig Wilson. The CHE types were gathered from the Patrick's Berth Detail from 2009 Port of Brisbane Shipping Handbook Berth Detail. Activity data were estimated using the total fuel use reported.

6.1.1.3 Australian Amalgamated Terminals (AAT)

The survey received listed the CHE equipment, lifting capacity, hours of operation and the total facility fuel consumption for petrol, diesel, liquefied petroleum gas (LPG). Further clarification revealed that the total diesel consumption includes equipment not solely used within the Port of Brisbane, such as trucks and trailer that drove outside of PoB property. It was confirmed that the petrol reported was used for onsite vehicle use only; therefore this data was used to determined onsite vehicle emissions.

The clarification indicated that some forklifts operate with LPG, but it remained unclear as to which ones they were. Due to this, it was assumed that all the CHE equipment operated with diesel fuel. The CHE lifting capacity was given and used to estimate engine power (HP or kW) from similar lifting capacity Hyster equipment specification sheets (Appendix D).

6.1.2 Container Parks and Depots

6.1.2.1 Chalmers Industries

The survey received did not report the CHE engine power (HP or kW). Assumptions of the engine power were based on similar lifting capacity Hyster equipment specification sheets (Appendix D).

6.1.2.2 P & O Trans Australia

CHE activity data was reported upon a site visit and further inquiries. The CHE data was reported for all Port of Brisbane P & O sites. The data received was complete except for the hours of operation of the LPG CHE and the CHE engine model year. Clarification revealed the typical use of the equipment to be 10 hours per day, 5 days per week, 52 weeks per year except for the workshop forklift which is operated significantly less at 2 hours per day, 5 days per week, 52 weeks per year.

6.1.2.3 Patrick Port Logistics

No CHE survey was received from Patrick Port Logistics. Due to minimal available information on sites total activity, the sites emissions were assumed to be the average of the all other reporting container parks and depots facilities.

6.1.3 Port of Brisbane Corporation Facilities

6.1.3.1 Brisbane Multimodal Terminal (BMT)

The CHE BMT activity data reported CHE fleet and yearly operational hours. To ensure confidential compilation of data, the BMT emissions are reported with the Stevedores operations.

6.1.4 Bulk Commodity

6.1.4.1 Graincorp Operations Limited

The survey received was complete.

6.1.4.2 Sunstate Cement Limited

Sunstate Cement Limited reported their CHE fleet and typical total monthly fuel use. Equipment hours of operation were estimated based on total monthly fuel use data. All engine power sizes were assumed based on similar engine capacity Hyster equipment specification sheets (Appendix D).

6.1.4.3 Caltex

Caltex reported their CHE fleet and typical operational hours via email. The engine was assumed to be manufactured in the year 2000 and have an engine power of 60 HP.

6.1.4.4 Queensland Bulk Handling

Queensland Bulk Handling reported their CHE fleet composition and the approximate total fuel combusted during a year. The operational hours (5,000 per year), engine manufactured year (2000) and engine power (60 HP) were all assumed.

6.1.4.5 Queensland Commodity Exports

No survey was received from Queensland Commodity Exports. Due to minimal available information on Queensland Commodity Exports site activity, the sites emissions were assumed to be the average of the all other reporting bulk commodity facilities.

6.1.5 Service Industry

6.1.5.1 Dredeco, Australian Customs, Hawkins Transport, ATS

Completed surveys were received.

6.1.5.2 QLD Water Police and Baulderstone

No surveys were for these facilities. Emissions were estimated assuming each facility emitted the average of the reporting service industry facilities.

6.1.6 Warehousing

6.1.6.1 ACFS

ACFS reported their CHE inventory and corresponding activity data.

6.1.6.2 IPS

IPS reported their CHE fleet and some activity data. The engine power capacities were assumed based on Hyster equipment specification sheets with similar lifting capacity (Appendix D).

6.1.6.3 Others

The other warehousing facilities did not report CHE data. Due to minimal available data, the emissions were estimated assuming each facility emitted the average of the reporting service industry facilities. These warehousing facilities are:

- Carter Holt Harvey and Linfox
- Steel Force
- Toll Chemicals
- Tzaneros and Port Gate Logistics
- Tzaneros West

6.2 Emission Factors

The following emission estimation method was used to estimate emissions from CHE equipment operating in the study area:

$$EMIS = EF_{g/kWh} \times P \times LF \times OH \div 1000$$

where EMIS represents total emissions (kg/year), $EF_{g/kWh}$ represents the emission factor (g/kWh), P is the rated engine power (kW), LF is a load factor (-) and OH represents the number of operational hours (hours/year). The CHE emission factors that were used in this project are provided in a spreadsheet called "CHE emission factors PBC LEI 2007-2008.xls".

CHE emission factors for diesel-powered CHE were replaced with US EPA NONROAD 2008 Model emission factors, where appropriate. Obtaining emission factors for CHE from the NONROAD Model is consistent with the emission estimation method outlined in the US EPA documents Current Methodologies and Best Practices in Preparing Port Emission Inventories (US EPA, 2006) and Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories – Cargo Handling Equipment (US EPA, 2009).

The NONROAD diesel emission factors were gathered from the publicly available downloadable EMSAF files (US EPA, 2008);

- EXHCO.EMF (for CO emissions);
- EXHNOX.EMF (for NO_x emissions);
- EXHPM.EMF (for PM_{10} emissions);
- EXHTHC.EMF (for total hydrocarbon emissions); and
- BSFC.EMF (for fuel consumption).

The NONROAD model emission factors are dependent on the equipment type and the US EPA diesel engine emission standards (Base - B, Tier 0 – T0, Tier 1 – T1, Tier 2 – T2, and Tier 3 – T3). The US EPA diesel emission standards have established emission rates for new diesel engines over a specific test procedure to be sold within the US. As years progress more stringent emission standards are evoked. Thus as old engines are retired the new replacement engines emit fewer emissions. Currently, Australia does not have non-road diesel engine emission requirements.

To utilise the NONROAD emission factors, it has been assumed the CHE engines within Australia are compliant to the US EPA diesel engine emission standards. It is also assumed that the whole of Australia's non-road diesel engine population has the same engine standards, based on manufactured year, as the US (US EPA, 2009).

Correspondence between the Port of Brisbane and a Cummins engine representatives confirm that most of Cummins engines are from the US (pers. comm. Sue Koreman). In addition, non-road diesel engine import data from the Australian Bureau of Statistics (ABS), for the 2004 financial year, show that the US is a main source of imported engines along with China and Japan (ABS, 2005). However, the ABS data do not cover the full range of non-road engines, and do not indicate whether the engines are new or used, nor whether the engines imported from the US meet US EPA engine emission regulations.

The assumed fractions of CHE engines compliant with the US emission standards, based on manufactured year and engine power, are included in Appendix E. These data are used to appropriately weigh the given NONROAD emission factors for CHE based on the US EPA engine standard and equipment type. The following equation was used to determine the NONROAD CHE emission factor based on engine manufactured year:

$$EF \quad = \sum_{ES} EF_{ES} \times F_{ES}$$

where EF represents the emission factor (g/kWh or g/l) for a given equipment type and manufactured year (g/kWh), ES represents the range of US EPA engine standards (B, T0, T1, T2, and T3), EF_{ES} represents the emission factor (g/kWh or g/L) for a given equipment type that meets the given US EPA emission standard, F_{ES} is the fraction of engines within the given US EPA engine emission standards.

Table 6.2 lists the CHE type located at the Port of Brisbane, the appropriate NONROAD source classification and the recommended load factors for CHE (US EPA, 2009).

Table 6.2: CHE Emission Factor Classification

CHE Type	Fuel	NONROAD Classification	Load Factor (LF)
Forklift	Diesel	Forklift	0.30
Crane	Diesel	Other Material Handling Equipment	0.59
Compressor	Diesel	Light Commercial Generator Set	0.51
Dozer	Diesel	Other Industrial Equipment	0.30
Empty Handler	Diesel	Other Industrial Equipment	0.59
End Loader	Diesel	Other Industrial Equipment	0.59
Full Handler	Diesel	Other Industrial Equipment	0.59
Generator	Diesel	Light Commercial Generator Set	0.51
Reach Stacker	Diesel	Other Industrial Equipment	0.30
Skid-Steer Loader	Diesel	Skid-Steer Loader	0.55
Straddle Ladder	Diesel	Other Material Handling Equipment	0.59
Terminal Tractor	Diesel	Terminal Tractor	0.57

The NONROAD model does not contain emission factors for LPG equipment, $PM_{2.5}$ emission factors, SO_2 emission factors, or GHG emission factors. LPG CHE emission factors were gathered from the NPI EET manual – *Combustion Engines Version 3.0* (NPI, 2008).

It is noted that for LPG powered forklifts, the emission factor is given in fuel consumption units (kg/l of fuel). This emission factor was converted to of a power based emission factory (kg/kWh) using the equation in Section 5.2 assuming a LHV of 46.1 MJ/kg, a density of 0.54 kg/l, and a thermal efficiency of 30% (see Table 3.1). Fuel-specific emission factors (g/kWh) for CO_2, CH_4, N_2O, CO_2-e, fuel consumption and SO_2 were computed using the fuel parameters presented in Section 3.

$PM_{2.5}$ emission factors were estimated based on the following assumptions:

- 95% of PM_{10} from LPG CHE are $PM_{2.5}$
- 95% of PM_{10} from petrol CHE are $PM_{2.5}$
- 90% of PM_{10} form diesel CHE are $PM_{2.5}$

SO_2 emissions were estimated using a mass balance technique and the fuel assumptions outlined in Section 3. GHG emissions, CO_2-e were calculated using the NGER approved methods - *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (NGER, 2008). Fuel-specific emission factors for GHGs (CO_2, CH_4, N_2O, CO_2-e) were computed using the fuel parameters presented in Section 3.

Finally, light-duty vehicles are not traditionally included in CHE emission inventories. At the request of PBC, the reported onsite vehicle data were included in the emission inventory. The fuel-based emission factors for these vehicles were taken from the NPI EET manual – *Combustion Engines Version 3.0* (NPI, 2008b) and are summarized in Table 6.3.

Table 6.3: Onsite Vehicle Emission Factors

Fuel Type	NPI EET		Fuel Use Emission Factor (kg/m^3)			
		CO	NO_x	PM_{10}	$PM_{2.5}$	THC
Diesel	Table 9	10	6.7	2.1	2	0.82
Petrol	Table 11	37	6.7	0.067	0.062	2.5
LPG	Table 13	35	3.4	-	-	4.1

SO_2 and GHG emission factors were calculated using the same methods as for the other CHE. For CHE activity data given as fuel use per year, the power based emission factors (g/kWh) were converted to fuel use emission factors (g/l of fuel) assuming the LHV, fuel density, and thermal efficiency as outlined in Section 3. A summary of all emission factors, by equipment type and engine emission standards are contained in Appendix F.

6.3 CHE Emission Inventory

A total of 304 individual pieces of CHE were reported during the Port of Brisbane emission inventory. Table 6.4 shows the total number and the engine power (Hp) breakdown of the reported CHE. The total number of CHE are under-reported, since some facilities only reported total fuel use, while other facilities reported no CHE information. Figure 6.2 graphically shows the reported CHE type and the engine manufactured year either reported, or assumed for the emission estimations. Table 6.5 contains the CHE emission inventory for the 2007/2008 year, based on the emission factors, activity data collected, and outlined assumptions. Table 6.6 contains the emission inventory for 2007/2008 listed by CHE types.

Table 6.4: PoB CHE Breakdown by Engine Power (Hp)

CHE Type	Fuel	Total Number of Pieces	Number by Engine Power Classification (Hp)		
			>300	300 - 150	<150
Forklift	Diesel	120	17	22	81
Forklift	LPG	52	0	0	52
Crane	Diesel	6	3	3	0
Compressor	Diesel	1	0	1	0
Dozer	Diesel	9	1	1	7
Empty Handler	Diesel	41	0	41	0
End Loader	Diesel	5	2	2	1
Full Handler	Diesel	22	2	16	4
Generator	Diesel	2	0	2	0
Reach Stacker	Diesel	15	11	2	2
Skid-Steer Loader	Diesel	1	0	0	1
Straddle Ladder	Diesel	27	0	27	0
Terminal Tractor	Diesel	3	0	0	3
Total		304	36	117	115

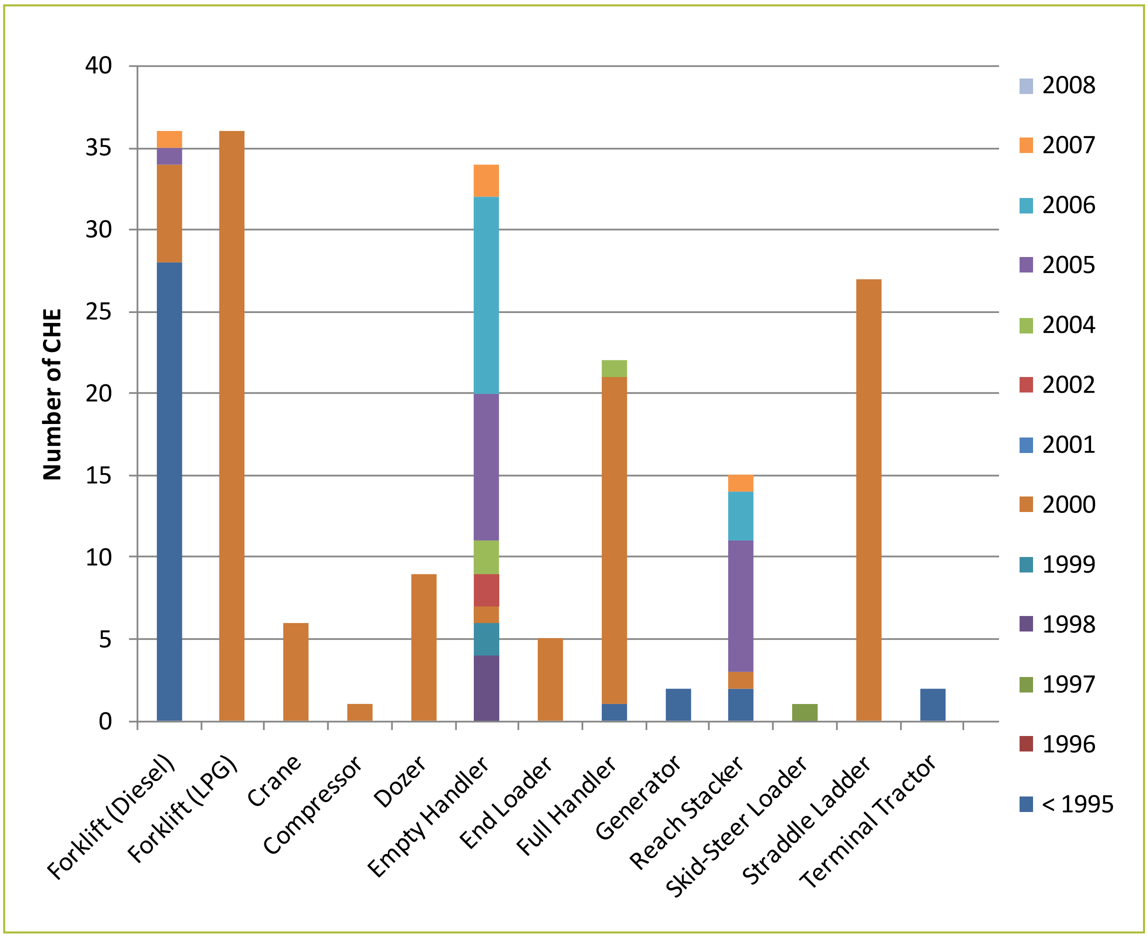


Figure 6.2: PoB CHE Breakdown by Engine Manufactured Year

Table 6.5: Total Emissions from CHE

Pollutant	Total CHE Emissions
	kg/year
Air Pollutants	
CO	159,107
THC	29,226
NO_x	388,229
SO_2	1,248
$PM_{10,exhaust}$	20,582
$PM_{2.5,exhaust}$	19,738
$PM_{10,non-exhaust}$	NA
$PM_{2.5,non-exhaust}$	NA
$PM_{10,total}$	20,582
$PM_{2.5,total}$	19,738
Greenhouse Gases	
CO_2	35,752,275
CH_4	6,162
N_2O	879
CO_2-e	38,388,568
Fuel Use	
Fuel Consumption	11,233,551

Table 6.6: Emissions from CHE by Type

CHE Type	Fuel	CO	THC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	CO_2-e
Forklift	Diesel	22,877	4,527	57,225	158	4,222	4,049	5,600,334
Forklift	LPG	11,062	1,452	17,284	75	0	0	1,046,404
Crane	Diesel	1,233	285	6,720	19	225	245	720,745
Compressor	Diesel	6	2	45	0	2	2	5,001
Dozer	Diesel	1,060	242	3,217	10	217	208	355,330
Empty Handler	Diesel	9,318	3,155	44,993	206	1,979	1,898	7,760,796
End Loader	Diesel	1,423	289	7,243	20	267	256	769,271
Full Handler	Diesel	5,351	1,003	24,231	77	872	836	2,534,337
Generator	Diesel	0	0	0	0	0	0	0
Reach Stacker	Diesel	4,305	865	19,984	82	739	680	3,051,007
Skid-Steer Loader	Diesel	239	61	208	1	38	36	16,684
Straddle Ladder	Diesel	40,144	5,496	81,243	234	4,779	4,583	7,472,482
Terminal Tractor	Diesel	189	36	388	1	38	37	29,827
Onsite Vehicle	Diesel	0	0	0	0	0	0	0
Onsite Vehicle	LPG	0	0	0	0	0	0	0
Onsite Vehicle	Petrol	2,568	172	463	10	5	4	119,652
Unclassified		59,332	11,641	124,985	355	7,199	6,904	8,906,698
Total		159,107	29,226	388,229	1,248	20,582	19,738	38,388,568

7 COMPARISON OF TRUCK, RAIL AND CHE EMISSIONS

Figure 7.1 graphically shows the contribution of each source category to total land-based emission levels.

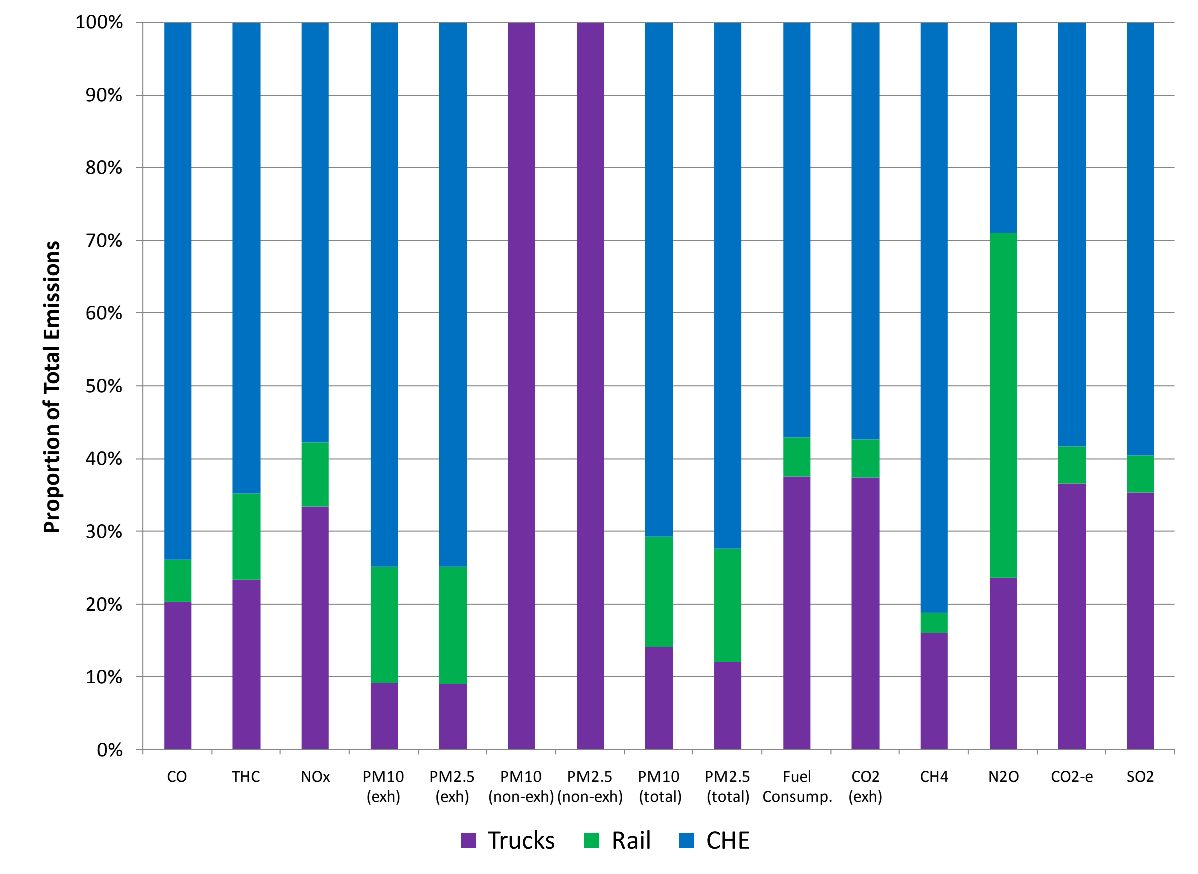


Figure 7.1: Contribution of Land-Based Source Categories to Total Emissions

From Figure 7.1 we observe the following:

- The LEI indicates that CHE is by far the most important emissions source. CHE causes the majority (> about 60%) of land-based emissions for CO, THC, CH_4, NO_x, PM_{10} (exhaust & total), $PM_{2.5}$ (exhaust & total) and SO_2.
- This is in part explained by the relatively large activity level of cargo handling equipment, i.e. it is estimated to account for slightly less than two-thirds of total fuel consumption in the study area. As a consequence, it accounts for the majority (slightly below 60%) of total land-based GHG emissions, expressed as CO_2-e.
- The next most important source is "trucks", which is estimated to account for about 40% of total fuel consumption and GHGs (CO_2-e) in the study area. However, their contribution to total land-based emissions is typically lower and varies between about 10% (exhaust PM) to 35% (SO_2), depending on the pollutant.
- The relatively low contribution of truck air pollutant emissions to total land-based emissions is due to their relatively low emission factors, which is shown in Figure 7.2. This is because road vehicle emissions are more tightly controlled than non-road sources, which has resulted in better engine optimisation and commonly used emission reduction technologies such as oxidation catalysts (CO, THC, PM) and EGR (NO_x).

- Rail is estimated to consume only 5% of total fuel in the study area and, as a result, estimated to produce only 5% of total GHGs (CO_2-e). The contribution to total land-based emissions varies between about 3% (CH_4) to 16% (total PM), depending on the pollutant. The contribution to N_2O (about 50%) seems very high and cannot be explained. The larger-than-expected contribution of rail to total emissions of THC, NO_x, PM, and in particular N_2O, is caused by the relatively high emission factors, as is shown in Figure 7.2.

Figure 7.2 shows average fuel-based emission factors (g/l) for each source category and pollutant. These mean emission factors are computed by dividing total predicted emissions for a particular pollutant and source category by total (estimated) fuel consumption for that source category.

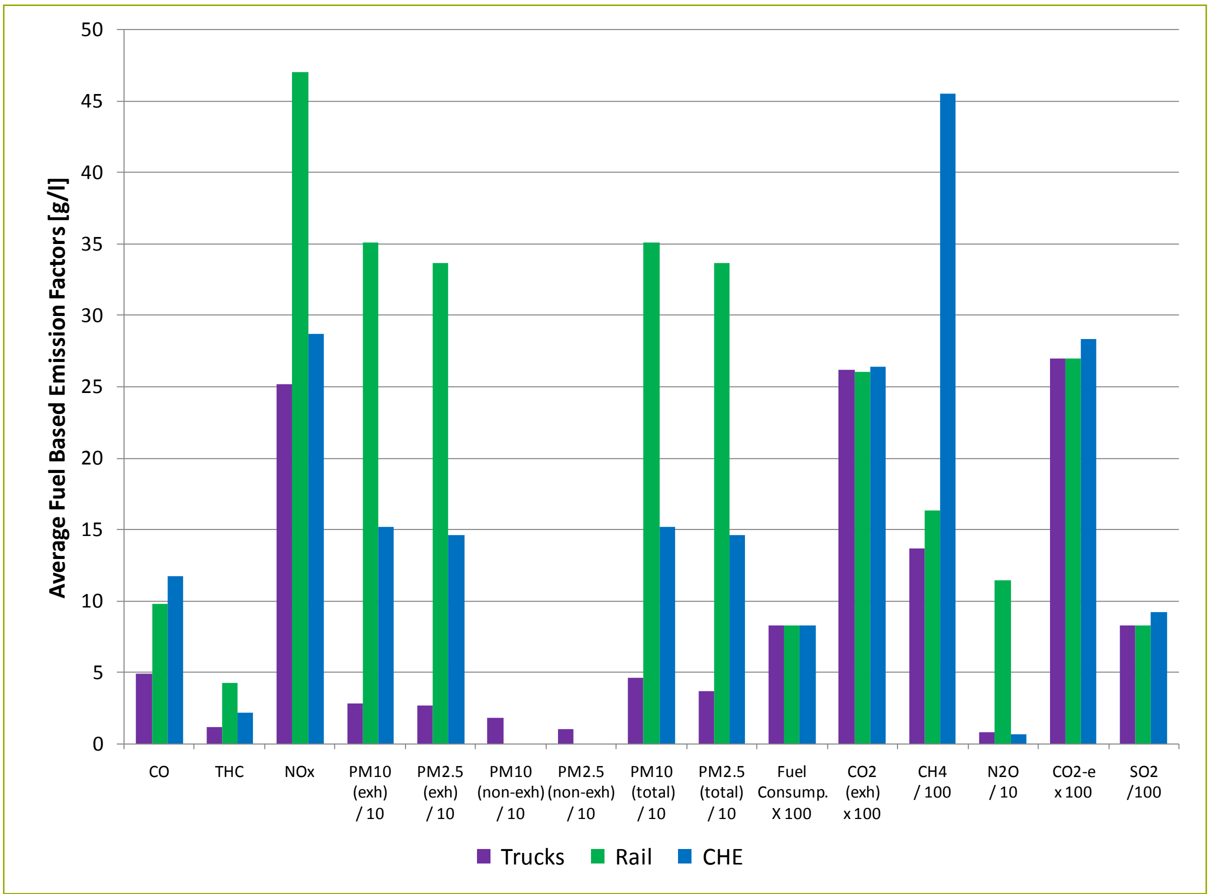


Figure 7.2: Mean Fuel-Based Emission Factors for Different Source Categories

From Figure 7.2 we observe that:

- The fuel-based emission factor for exhaust PM_{10} and $PM_{2.5}$ is a factor of about 12 higher for rail when compared to road. The difference reduces to a factor of about 7-9 for total PM_{10} and $PM_{2.5}$ emissions, after taking into account non-exhaust PM emissions for trucks.
- The fuel-based emission factor for exhaust CO and THC are a factor of about 2-4 higher for both rail and CHE when compared with trucks. For NO_x CHE and truck emission factors are comparable.
- Fuel-based emission factors for fuel consumption (effectively density), CO_2, CO_2-e, and SO_2 are similar for all sources, which is to be expected as the bulk of the fuel used is commercially available diesel for each source.

- The fuel-based emission factor for nitrous oxide (N_2O) is a factor of 14 higher for rail when compared to road. There is no technological explanation for this.

8 COMPARISON OF LAND-BASED AND WATER-BASED EMISSIONS

Finally, to put these results in more perspective, Figure 8.1 show the relative contribution of both water-based (AMC, 2009) and land-based (this project) sources to total emission levels. It is clear that vessels generate the majority of emissions in the study area, i.e.

- about 100% for SO_2,
- about 90% for PM,
- about 80% for THC, NO_x, CO_2, CO_2-e, and
- about 60% for CO, CH_4 and N_2O.

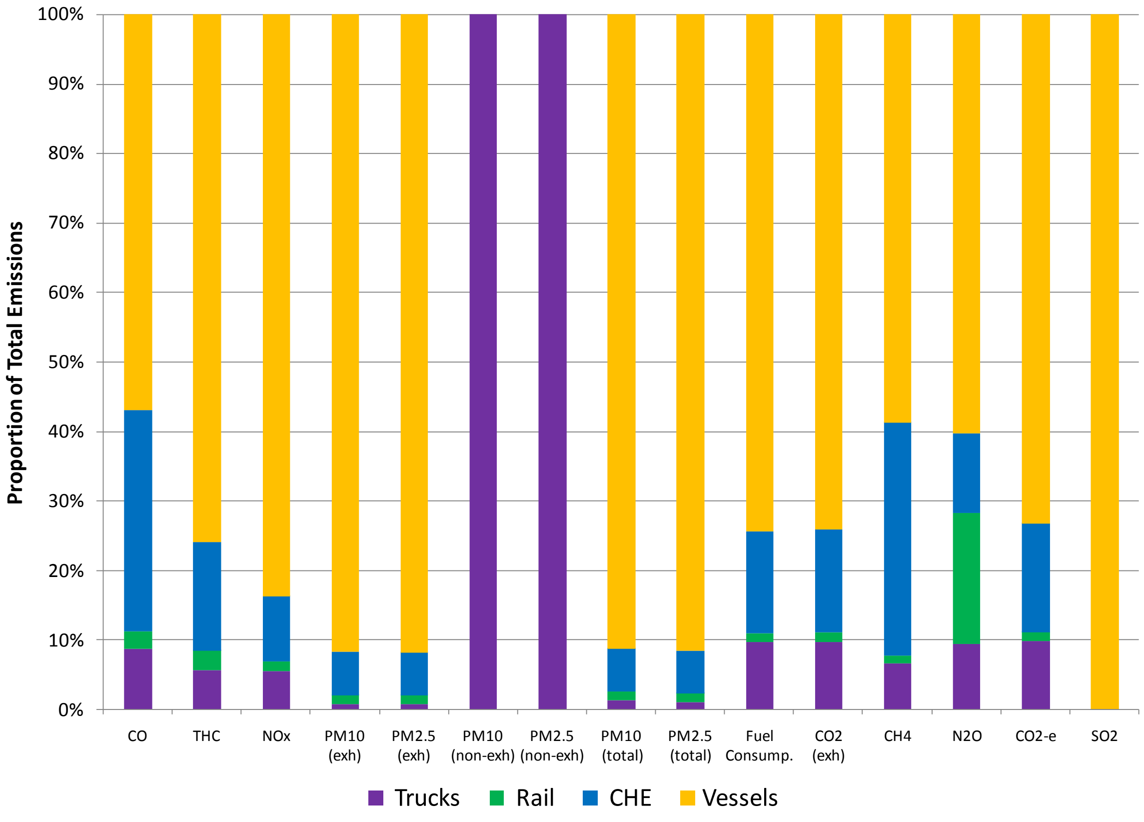


Figure 8.1: Contribution of All Source Categories to Total Emissions

We note, though, that these results can be quite different when health impacts are considered. For instance, emissions from trucks and CHE are typically emitted close to workers and/or the general population leading to significant exposure to these pollutants and their harmful effects. In contrast, emissions from vessels will typically be emitted on open water, relatively far away from the population, which provides ample time for emissions to be diluted before they reach the general population. So in terms health effects, land-based emissions are more important than one would think on the basis of their contribution to total emission levels.

9 FUGITIVE EMISSIONS

A review of all facilities and operations was conducted for the study area. Potential fugitive emission sources were identified using the National Pollutant Inventory (NPI) database and inspection of site operations. Potential fugitive emission sources were identified as follows:

- wind erosion of particulates from stockpiles;
- emissions of particulates from bulk material handling; and
- emissions of volatile organic compounds from volatile material loading.

Potential emission sources for each facility are detailed in Table 9.1

Table 9.1: Potential Fugitive Emission Sources at Port of Brisbane

Facility	Potential for Significant Fugitive Emissions	Potential Emission Sources	Pollutants released	Significance
Truck stop	Yes	Refuelling	VOCs	Insignificant (diesel refuelling non-volatile)
Water police	Yes	Refuelling	VOCs	Insignificant (diesel refuelling non-volatile)
P B Towage	Yes	Refuelling	VOCs	Insignificant (diesel refuelling non-volatile)
Svitzer Australia Tug Base	Yes	Refuelling	VOCs	Insignificant (diesel refuelling non-volatile)
Queensland Bulk Handling	Yes	Bulk material handling, wind erosion	PM	Significant (NPI report)
Coal wharf	Yes	Bulk material handling	PM	Significant
Sunstate Cement	Yes	Bulk material handling, wind erosion	PM	Significant (NPI report)
Caltex (Crude Oil Wharf)	Yes	Volatile material handling	VOCs	Significant
Queensland Commodity Exports	Yes	Bulk material handling, wind erosion	PM	Significant
Graincorp Operations Limited	Yes	Bulk material handling	PM	Significant
Grain Wharf	Yes	Bulk material handling	PM	Significant
Patrick Autocare	Yes	Refuelling	VOCs	Insignificant
Port of Brisbane Operations Base	Yes	NA	NA	NA
Toll chemicals	No	NA	NA	NA
Steel force	No	NA	NA	NA
Osprey	No	NA	NA	NA
ACFS	No	NA	NA	NA
Carter Holt Havey & Linfox	No	NA	NA	NA
Dredeco	No	NA	NA	NA
Baulderstone	No	NA	NA	NA
Hawkins Transport & M1 Cat Ferry	No	NA	NA	NA

Table 8.1: Potential fugitive emission sources at Brisbane Port (Continued)

Facility	Potential for Fugitive Emissions	Potential Emission Sources	Pollutants released	Significance
Australian Amalgamated Terminals	No	NA	NA	NA
DP World Container World	No	Other emissions are from vehicle combustion	NA	NA
Brisbane Autostand Terminal (Patrick)	No	NA	NA	NA
AAT Overflow Area	No	NA	NA	NA
Prixcar	No	NA	NA	NA
Car Storage	No	NA	NA	NA
Patrick Autocare	No	NA	NA	NA
Australian Customs	No	NA	NA	NA
Container Link	No	NA	NA	NA
Chalmers Industries	No	NA	NA	NA
ATS Developments	No	NA	NA	NA
PBC Landcare	No	NA	NA	NA
P & O Trans Australia	No	NA	NA	NA
Patrick Port Services	No	NA	NA	NA
Reclamation Area	No	NA	NA	NA

10 CONCLUSIONS

This report presented the results of a baseline landside emissions inventory (LEI) for the Port of Brisbane precinct. The emission inventory has been developed for greenhouse gases (CO_2-e, CH_4, N_2O, CO_2) and relevant air pollutants (CO, THC, NO_x, SO_2, PM_{10}, $PM_{2.5}$) for the base year 2007/08. It has estimated emissions for on-road trucks, cargo handling equipment (CHE) and rail.

The fuel consumption and emission factors have been based on empirical Australian data to the extent these are available. Relevant transport activity data was collected and processed from several sources.

The LEI indicates that CHE is by far the most important emissions source, as it generally causes the majority (60-80%, depending on the pollutant) of land-based emissions in the study area. This is at least in part explained by:

- the relatively large activity level of cargo handling equipment, i.e. it is estimated to account for slightly less than two-thirds of total fuel consumption in the study area; and
- the lack of emission standards for non-road equipment in Australia.

The next most important source is 'trucks', which is estimated to account for about 35% of total fuel consumption and GHGs (CO_2-e) in the study area. However, their contribution to total land-based emissions is typically lower and varies between about 10% to 35%, depending on the pollutant. The relatively low contribution of truck emissions to total land-based emissions is due to their relatively low emission factors. This is because road vehicle emissions are more tightly controlled than non-road sources, which has resulted in better engine optimisation and commonly used emission reduction technologies such as oxidation catalysts and EGR.

Rail is estimated to consume only 5% of total fuel in the study area and, as a result, estimated to produce only 5% of total GHGs (CO_2-e). The contribution to total land-based emissions varies between about 3% to 16%, depending on the pollutant. The contribution to N_2O (about 50%) seems very high and cannot be explained. The larger-than-expected contribution of rail to total emissions of THC, NO_x, PM, and in particular N_2O, is caused by relatively high emission factors.

11 RECOMMENDATIONS FOR FURTHER WORK

A number of aspects of this study and assumptions we had to make can be further examined and possibly improved. We have listed a number of recommendations for further work in this section. We generally recommend an examination of the applicability of new and updated emission estimation methods for different transport modes to the Port area, such as those that are discussed in the ERMES group ("European Research group on Mobile Emission Sources", kick-off was on 22-23 June in Brussels), of which we are member.

11.1 Cargo Handling Equipment

Given the relative importance of CHE we recommend to:

- further examine and analyse CHE activity data in the Port Area;
- further examine and verify emission standard equivalencies of the CHE equipment used in Australia; and
- perform a review of available CHE emission factor models in Europe, Japan and the US.

11.2 Trucks

- Further data collection with respect to local fleet composition is recommended as this would provide more certainty to the local fleet composition that was developed for this project where we used the available data sources (WIM data, camera data, vehicle registration data, O/D data). We recommend to add license registration numbers to the data collected at the WIM site and other strategic locations, as this would allow a direct linkage of e.g. WIM data (number of trailers, axle groups, axles) to vehicle registration data (year of manufacture, fuel type, GVM/GCM).
- A substantial amount of new empirical emissions data for Australian vehicles is becoming available. This creates an opportunity to update the emission factors used in this project. This is particularly important for the specific vehicle configurations (B-doubles, super-B-doubles) used in the Port area, which are effectively extrapolations of emission factors for lighter trucks.
- There may be an opportunity to develop emission factors for a more detailed vehicle classification (e.g. Austroads) to enable a more detailed and accurate calculation of truck emissions that, importantly, aligns better with the structure of traffic data collected in the field.
- Further examination of different transport categories (e.g. bulk, container, perhaps more detailed) and their differences in terms of vehicle loading (total weight) and driving behaviour (e.g. idling) is highly recommended. This information can then be used to fine-tune the current emission factors and activity data. This will lead to an improved emission inventory and provides PBC with more accurate and more diversified information on the emission impacts of the various truck operations in the Port area.
- Any future driver surveys are recommended to have more detail, for instance including questions on model year of the truck and more details on retrofitting.
- Any future surveys of truck usage or analysis of GPS data are recommended to specifically target rigid vehicles, for which little data is currently available.
- A systematic programme for collecting classified automatic traffic counts is recommended for all of the ports internal road network – perhaps on a rolling program which ensures that all roads are counted at least once every 3-5 years.

- Further examination of a number of traffic related aspects is recommended:
  - the proportion of on-island “light” and “heavy” Super B-Doubles;
  - data on vehicle loading by vehicle type, including information empty weight;

11.3 Rail

- The contribution to N_2O emissions from rail (about 50%) is very high and cannot be explained. Further examination of N_2O emission factors and possible modification of the emission inventory is recommended.
- A further attempt to obtain more detailed rail activity data for the Port Area.
- Perform a review of available overseas rail emission factor models.

12 REFERENCES

AMC, 2009. *Waterside Air Emission Inventory for the Port of Brisbane 2007/2008*, Australian Maritime College, by Laurie Goldsworthy and Martin Renilson, Draft Report, April 2009.

ABS, 2005. *Merchandise Import Trade Data for 2004 Calendar Year*, Australian Bureau of Statistics.

ABS, 2007. *Motor Vehicle Census*, Australian Bureau of Statistics, 31 March 2007, Report No. 9309.0.

Beer, T., et al., 2001. *Comparison of Transport Fuels*, Prepared for Australian Greenhouse Office, Final Report, EV45A/2/F3C.

DCC, 2008. *National Greenhouse Accounts (NGA) Factors*, Australian Government, Department of Climate Change, November 2008.

DEWHA, 2008. *Emission Estimation Technique Manual for Railway Yard Operations*, Version 2, Australian Government, Department of Environment, Water, Heritage and the Arts (DEWHA), June 2008.

EA, 2000. *Emissions Estimation Technique Manual for Aggregated Emissions from Motor Vehicles*, Environment Australia, 22 November 2000 – Version 1.0.

EEA, 2007. *EMEP/CORINAIR Emission Inventory Guidebook - 2007*, European Environment Agency, Technical report No 16/2007.

INFRAS, 2007. *Road Emission Model*, INFRAS, Deliverable No. 13, October 2007.

NGER, 2008. *National Greenhouse and Energy Reporting (Measurement) Determination 2008.* . http://www.frli.gov.au/ComLaw/Legislation/LegislativeInstrument1.nsf/0/EA12365542EAC45ACA257475000EF6B7/$file/F2008L02309.pdf, accessed May 2009.

NPI, 2003. *National Pollutant Inventory Emission Estimation Technique Manual for Combustion Eninges. Version 2.3*. June 2003. Environment Australia. Canberra, Australia. http://www.npi.gov.au/handbooks/approved_handbooks/pubs/combustion-engines.pdf, accessed May 2009.

NPI, 2000. *National Pollutant Inventory Emission Estimation Technique Manual for Maritime Operations. Version 2.0*. July 2008. Environment Australia. Canberra, Australia. http://www.npi.gov.au/handbooks/approved_handbooks/pubs/maritime-operations.pdf, accessed May 2009.

NPI, 2008. *National Pollutant Inventory Emission Estimation Technique Manual for Combustion Engines. Version 3.0*. June 2008. Environment Australia. Canberra, Australia. http://www.npi.gov.au/handbooks/approved_handbooks/pubs/combustion-engines.pdf, accessed May 2009.

PAEHolmes, 2009. *Work Plan Phase 2 – Landside Emission inventory for the Port of Brisbane Precinct 2007/2008 – Phase 1 Results and Phase 2 Workplan*, 1 June 2009.

Pekol, A., Anyon, P., Hulbert, M., Smit, R., Ormerod, R., Ischtwan, J., 2003. South East Queensland motor vehicle fleet air emissions inventory 2000, 2005, 2011, in *Linking Air Pollution Science, Policy and Management: Proceedings of National Clean Air Conference*, Newcastle, Australia.

SD+D, 2010. *POB Truck Movements for Air Quality Estimation Based on Container O-D Survey March 2007*, prepared for Port of Brisbane, March 2010.

Smit, R., 2008. Errors in model predictions of NO_x traffic emissions at road level – Impacts of input data quality, in *Air Pollution XVI*, 116, eds. Brebbia, C.A., Longhurst, J.W.S., WIT Press, ISBN 978 1 84564 127 6, 255-269.

Smit, R., McBroom, J., 2009. Use of microscopic simulation models to predict traffic emissions -Technical Note, *Road and Transport Research*, 18 (2), June 2009, 49-54.

Smokers, R. & Smit, R. 2004, *Compatibility of Pure and Blended Biofuels with Respect to Engine Performance, Durability and Emissions*, SenterNovem Report 2GAVE04.01, http://gave.novem.nl/novem_2005/index.asp?id=32

Starcrest, 2007. *Port of Los Angeles inventory of Air Emissions*, Starcrest Consulting Group, September 2007.

US EPA, 2006. *Current Methodologies and Best Practices in Preparing Port Emission inventories – Final Report. January 2006*, ICF Consulting for the Environmental Protection Agency, United States.

US EPA, 2008. *NONROAD2008 Model*, April 2008, Environmental Protection Agency, United States, http://www.epa.gov/oms/nonrdmdl.htm#model, accessed June 2009.

US EPA, 2009. *Current Methodologies in preparing Mobile Source Port-Related Emission Inventories – Cargo Handling Equipment*, April 2009, ICF Consulting for the Environmental Protection Agency, http://www.epa.gov/ispd/sectorinfo/sectorprofiles/ports/ports-emission-inv-april09.pdf, accessed June 2009.