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Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006

Energy (Transport)

National Greenhouse Gas Inventory Committee

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http://www.ipcc-nggip.iges.or.jp.

Suggestions and comments would be appreciated. They should be addressed to the Manager, Australian National Greenhouse Gas Inventory, Emissions Analysis Team, Department of Climate Change or sent to ageis@climatechange.gov.au.

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Foreword

This inventory methodology workbook presents the Australian methodology to estimate greenhouse gas emissions and sinks for the transport sector. It is part of a series that includes:

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Stationary Sources)

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Transport)

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Fugitive Fuel Emissions)

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Industrial Processes

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Solvents

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Agriculture

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Land Use, Land Use Change and Forestry

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Waste

The methodology in this workbook was developed with input from researchers and other experts specialising in greenhouse gas emissions from transport sources. It is based on the methodology first presented in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Energy, Workbook for Transport (Mobile Sources),* National Greenhouse Gas Inventory Committee, Workbooks 2.0 (1994) and 2.1 (1998), Canberra. Contributors to the development of the original methodology are listed in those Workbooks.

The development of Australia's inventory methodologies and the compilation of Australia's national inventories are guided by the National Greenhouse Gas Inventory Committee, comprising representatives of the Australian, State and Territory governments.

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACS	Australian Customs Service
ADO	Automotive diesel oil
ADR	Australian Design Rule
AEC	Australian Environment Council
AGA	Australian Gas Association
AGPS	Australian Government Publishing Service
AIP	Australian Institute of Petroleum
ALPGA	Australian Liquefied Petroleum Gas Association
ANZSIC	Australian and New Zealand Standard Industrial Classification
Avgas	Aviation gasoline
Avtur	Aviation turbine fuel
BTCE	Bureau of Transport and Communications Economics
CFCs	Chlorofluorocarbons
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DEST	Department of the Environment, Sport and Territories
DME	Department of Minerals and Energy of New South Wales
EPA	The Environment Protection Agency
EPANSW	Environment Protection Authority of New South Wales
EPAV	Environment Protection Authority of Victoria
ERDC	Energy Research & Development Corporation
FCAI	Federal Chamber of Automotive Industries
FORS	Federal Office of Road Safety
FTP	Federal Test Procedure
GCV	Gross calorific value
IDF	Industrial diesel fuel
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied petroleum gas
NA	Not applicable
NAV	Not available
N_2O	Nitrous oxide
NCV	Net calorific value
NG	Natural gas
NGGIC	National Greenhouse Gas Inventory Committee
NMVOC	Non-methane volatile organic compound
NOx	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
pers. comm.	personal communication
RVP	Reid Vapour Pressure
SMVU	Survey of Motor Vehicle Use
VKT	Vehicle Kilometres Travelled

Units

The units mainly used in the workbook are joules (J), grams (g), metres (m) and litres (l). Standard metric prefixes used in this workbook are:

kilo (k)	=	10^3 (thousand)
mega (M)	=	10^6 (million)
giga (G)	=	10^9 (billion)
tera (T)	=	10^{12}
peta (P)	=	10^{15}

One gigagram (Gg) equals one thousand tonnes or one kilotonne (kt). One million tonnes or one megatonne (Mt) is equal to one thousand gigagrams. One kilogram per gigajoule (kg/GJ) is equal to one gigagram per petajoule (Gg/PJ). One terametre is equal to one billion kilometres.

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Introduction

Australia's national greenhouse gas inventory is prepared annually by the Department of Climate Change in accordance with both the IPCC *Revised 1996 Guidelines for National Greenhouse Gas Inventories* (IPCC 1997) and the *IPCC Good Practice Guidance* (IPCC (2000) while taking into account Australian conditions. Documenting the methods used in the estimation of emissions for the inventory enhances transparency and improves the comparability of estimates with those reported in the inventories produced by other countries.

The methods and emission factors used by Australia to estimate annual emissions of greenhouse gases from activities associated with *Transport* are documented in this workbook. It covers the UN Framework Convention on Climate Change (UNFCCC) reporting categories:

- *Civil aviation (1A3a) (including international air transportation (1A3a.i) and domestic air transportation (1A3a.ii));*
- *Road Transportation (1A3b), comprising*
    - *passenger cars (1A3b.i) subdivided by age band*
    - *light commercial vehicles (1A3b.ii)*
    - *medium duty trucks (1A3b.iii)*
    - *heavy duty trucks (1A3b.iv)*
    - *buses (1A3b.v)*
    - *motorcycles (1A3b.vi)*
- *Railways (1A3c)*
- *Navigation (1A3d)*
    - *international marine transportation (1A3d.i)*
    - *domestic marine transportation (1A3d.ii), comprising*
        - *coastal shipping*
        - *pleasure craft (recreational boating)*
        - *ferries*
        - *commercial fishing*
- *Other transportation (1A3e), comprising off-road recreational vehicle activity*

The focus of this workbook is on the emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen (NOx), carbon monoxide (CO), non methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2) from all mobile combustion engines. These include not only *road*, *railways*, *civil aviation* and *navigation* transportation but also *off road vehicles*, *military transport* and *mobile* and *utility engines* such as lawn mowers, chain saws, portable generators and mobile compressors. Greenhouse gas emissions resulting from consumption of international bunker fuels are also estimated, where the fuels were uplifted in Australia.

This workbook is one of three workbooks for the Energy sector. The estimation of greenhouse gas emissions from combustion of fuels in the Energy sector from stationary sources is covered in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Stationary Sources)*. Greenhouse gas emissions from activities associated with fuel production, transmission, storage and distribution are documented in the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Fugitive Fuel Emissions)*.

A number of mobile source categories have been allocated to the stationary source inventory because the current national data collection methods do not allocate this fuel to the transport sector but rather to the specific ANZSIC class in which it is used. In particular, emissions from miscellaneous off-road vehicles used in specific ANZSIC classifications (such as tractors and other farm vehicles, forestry vehicles, quarry trucks and front-end loaders, construction equipment, and forklifts), are allocated to the corresponding ANZSIC group and accounted for in the *Stationary Energy* sector. Emissions from all other off-road mobile sources, however, such as unregistered trail bikes and recreation vehicles, competition vehicles, mobile utility engines (such as lawn-mowers, chain-saws, portable generators and mobile compressors), and military transport are covered in this workbook.

General Approach

Greenhouse gas emissions from mobile sources consist of the gaseous products of engine fuel combustion (exhaust emissions) and gas leakage from vehicles (fugitive emissions), essentially comprising:

- CO_2 emissions due to the oxidation of fuel carbon content during fuel combustion;
- CH_4, N_2O, NOx, CO, SO_2 and NMVOCs emissions resulting from incomplete fuel combustion, reactions between air and fuel constituents during fuel combustion, and post-combustion reactions; and
- fugitive emissions of NMVOCs, due to fuel evaporation.

The estimation of mobile source emissions is complex since emission levels depend on a large number of factors, including:

- class of vehicle and type of pollution control equipment fitted;
- type of fuel consumed and the average rate of fuel consumption;
- condition of the vehicle, which is influenced by the age and the level of maintenance; and
- operating conditions such as driver behaviour, weather conditions, road type and traffic levels.

The IPCC distinguishes between competing methodological designs by a Tier structure that identifies different levels of methodological complexity. Australia uses a mix of Tier 1 and Tier 2 estimation methodologies in the transport sector (Table 1).

Table 1: Summary of methods and emission factors used to estimate emissions for Transport

GREENHOUSE GAS SOURCE AND SINK CATEGORIES: Transport		CO_2		CH_4		N_2O	
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A3a	Civil Aviation	T2	CS	T2	CS/D	T2	CS/D
1A3bi-v	Road Transportation	T2	CS	T3	CS/D	T3	CS/D
1A3b vi	Road Transportation – Motor cycles	T2	CS	T1	CS/D	T1	CS/D
1A3c	Railways	T2	CS	T1	D	T1	D
1A3d	Navigation (Domestic)	T2	CS/D	T2	D	T2	D
1A3e	Other Transport	T2	CS	T1	D	T1	D
1A4	Other sectors	T2	CS	T2	D	T2	D
1A5b	Military	T2	CS/D	T2	CS	T2	CS

Notes: T1 = Tier 1. T2 = Tier2. T3 = Tier3. CS= Country-specific. D= IPCC default. The distinction between Tier 1 methods and those of Tiers 2 and 3 rests mainly on the reliance of the first on widely available fuel supply data which, by its nature, takes no account of the combustion technology to which the fuel is delivered. Distinguishing between Tiers 2 and 3 is less easily done as there is a steadily increasing degree of refinement and detail. Tier 2 methods may be regarded as those dividing fuel consumption on the basis of sample or engineering knowledge between technology types which are sufficiently homogenous to permit the use of representative emission factors. Tier 3 methods generally estimate emissions from activity figures (kilometre travelled or tonne-kilometre carried, not fuel consumption) and specific fuel efficiency or fuel rates or, alternatively, using an emission factor expressed directly in terms of a unit of activity. (IPCC 1997, page 1.47)

Carbon dioxide emissions from the combustion of transport fuels are calculated by Tier 1 methods by multiplying the fuel consumption for each type of mobile engine by a country specific or default CO_2 emission factor (in g/MJ) and an oxidation factor. The oxidation factor represents the proportion of fuel oxidised during combustion. The balance of the fuel (one minus the oxidation factor) is converted into solid products such as soot.

This estimation method assigns the total carbon content of the fuel to CO_2 emissions and solid products, even though under actual engine operating conditions a portion of the carbon in the fuel is released as CH_4, CO and NMVOCs, which are separately accounted for. This numerically small double count makes the estimation of CO_2 emissions more straightforward, and is also justified to some extent by the fact that carbon emitted as CH_4, CO or NMVOCs eventually converts to CO_2 in the atmosphere. The conversion occurs over a relatively short period compared to the lifetime of CO_2 in the atmosphere (which is greater than 100 years).

Fuel evaporation from petrol fuelled vehicles is related to the volatility of the fuel. This varies from season to season, from state to state, and with the ambient temperature in which the vehicle operates. It also varies with the means of evaporation control built into the vehicle, which in general depends on the vehicle's age. Evaporative emission factors are calculated taking these variables into account, and emissions are calculated by multiplying the activity data (vehicle kilometres travelled or number of vehicles) by the calculated emission factor. Information on the evaporation or escape of other fuel types is not available at the present time, and are considered to be negligible.

Non-CO_2 greenhouse gas emissions from the combustion and evaporation of fuels in mobile engines are calculated using Tier 3 technology-specific methods for passenger cars, light commercial vehicles, heavy vehicles and aviation and are calculated by multiplying activity data (either fuel consumption or distance travelled) by the appropriate conversion rate or emission factor. Non-CO2 emission factors are expressed as grams of gas emitted per megajoule of energy used (g/MJ) or grams emitted per vehicle kilometre travelled (g/km). In the case of SO_2, the emission factor is derived from knowledge of the fuel sulphur content.

All emission factors relating to energy consumption are given in terms of gross calorific value (GCV), rather than the OECD standard of net calorific value (NCV), since the Australian Bureau of Agricultural and Resource Economics (ABARE) reports energy use in terms of GCV. Emission factors given in NCV terms (such as those provided by OECD 1991 and IPCC 1997 Volume 3) are reduced by 5 per cent for solid or liquid fuels and 10 per cent for gaseous fuels to provide equivalence with the GCV energy data (as suggested by IPCC 1997 Volume 3).

The emission factors summarised in Tables A.2 to A.8 are national average values. Emission factors have been calculated on the basis of Australian vehicle characteristics wherever possible. Where data specific to Australian conditions have not been available, emission factors have been derived from the default estimates given in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and the *IPCC Good Practice Guidance* (IPCC 2000). For mass calculations (involving molecular weights), it is assumed that NOx emissions have the empirical formula NO_2.

General Methodology

The emission level of a greenhouse gas from fuel combustion in the engines of a mobile source, using a specified fuel type, is calculated by:

$$E(l)_{hijk} = A^{u}_{hijk} \times F(l)^{u}_{hijk} \quad (1)$$

for $u = 1$ or 2 and $l = 1$ to 7

Where $E(l)_{hijk}$ is the emission of greenhouse gas l in gigagrams (Gg), from a mobile source of category i and class j (within sector h), using fuel type k *(see Tables 2 and 3 below for detail)*;

A^{u}_{hijk} is the activity level, where u=1 refers to energy consumption in petajoules (PJ) and u=2 refers to distance travelled in kilometres (km); and

$F(l)^{u}_{hijk}$ is the emission factor, in units of grams of gas l emitted per megajoule of energy use (g/MJ) for u=1, and grams of gas l emitted per kilometre travelled (g/km) for u=2.

The required form of the equation (whether u equals 1 or 2) for a particular calculation depends on the units of the emission factor specified for that calculation. Emission factors for CO_2 from road vehicles are usually specified in terms of g/MJ, whereas those for non-CO_2 gases from road vehicles are usually specified in terms of g/km.

Once the combustion emissions from type of mobile source have been calculated, they are summed to derive total emission levels by category and sector:

$$E(l)_{hi} = \sum_j \sum_k E(l)_{hijk} \qquad (2)$$

$$E(l)_h = \sum_i E(l)_{hijk} \qquad (3)$$

Where $E(l)_{hi}$ is the emission of greenhouse gas l (in Gg), from mobile source category i (within sector h); and

$E(l)_h$ is the total emission of greenhouse gas l (in Gg) from sector h *(see Tables 2 and 3 below)*.

Then summing over the sectors (from $h = 1$ to 6) gives:

$$E(l) = \sum_h E(l)_h \qquad (4)$$

Where *E(l)* is the total emission of greenhouse gas l (in Gg) from mobile sources.

Table 2 summarises mobile source sectors, categories, classes, fuel types and greenhouse gas emission species. The notation of the algorithms refers to the values of the appropriate subscripts (h, i, j, k, or l) given in Table 2. The superscript u indicates whether the activity levels are in energy units (u=1) or vehicle kilometre travelled units (u=2).

Table 3 describes the purpose of each algorithm.

Table 2: Summary of mobile source categories, fuel types, greenhouse gases

Mobile Sources Sector	h	Category	i	Age Band	j	Fuel Type	k	Greenhouse Gas	l	Road Type	m	Mode of operation	n
Civil Aviation	1					Automotive Gasoline	1	CO_2	1				
		Domestic Aviation	1		1	ADO	2	CH_4	2				
		International Aviation	2		1	LPG	3	N_2O	3				
Road Transportation	2					Avgas	4	NO_x	4	Urban	1	Hot	1
		Passenger Vehicles	1	Post-1997	4	Avtur	5	CO	5	Non-urban	2	Cold	2
		Light Commercial Vehicles	2	1985-1997	1	IDF		NMVOC	6				
				1976-1985	2	Fuel Oil	6						
				pre-1976	3	Natural Gas	7	SO_2	7				
		Medium duty trucks	3			Black Coal	8						
		Heavy Duty Trucks	4		1								
		Buses	5		1								
		Motorcycles	6		1								
					1								
					1								
Railway Transport	3												
Navigation	4												
		Domestic Marine Transportation	1										
				Pleasure craft	1								
				Ferries	2								
				Fishing	3								
				Coastal Shipping	4								
		International Marine Transportation	2		1								
Military Transport	5												
		Air	1		1								
		Land	2		1								
		Water	3		1								
Other Mobile Sources	6												
		Recreational Vehicles	1		1								
		Farm Equipment	2										
		Industrial Equipment	3										
		Mining Equipment	4										
		Utility Engines	5										

Table 3: Description of algorithms

Algorithm	Purpose
(1)	Calculates emissions of a specified greenhouse gas from combustion of a particular fuel in a particular sector and source category.
(2)	Calculates emissions of a specified greenhouse gas from a particular sector and source category by summing over fuel types.
(3)	Calculates emissions of a specified greenhouse gas from a particular sector by summing over source categories.
(4)	Calculates emissions of a specified greenhouse gas from transport (mobile sources) by summing over sectors.
(5)	Calculates total activity for a specified fuel type in a particular source category by summing over classes.
(6)	Calculates total activity for a specified fuel type in a particular sector by summing over source categories.
(7)	Calculates total activity for a specified fuel type for all mobile sources by summing over sectors.
(8) - (34)	Assign activity levels to sectors and categories based on energy consumption data.
(35)	Apportions road transport fuel use among vehicle categories.
(36)	Converts activity data from petajoules to terametres (that is, calculates vehicle distance travelled from fuel use).
(37)-(39)	Groups petrol passenger car proportions of total distance travelled by vehicle age into age classes.
(40)	Calculates the average rate of fuel consumption for petrol passenger cars.
(41)	Apportions energy use by petrol passenger cars among vehicle age classes.
(42)	Converts activity data from petajoules to terametres for petrol passenger cars.
(43)	Calculates CO_2 emissions using fuel consumption figures.
(44)	Calculates non CO_2 emissions for road vehicles
(45)	Calculates road vehicle emission factors according to accumulated VKT

Activity Data

The following algorithms apportion total annual fuel consumption obtainable from ABARE, by fuel type (k) for mobile sources (denoted by $A^{u=1}k$), between the various mobile categories (i).
As with equations (2) and (3), totals and subtotals of activity levels by fuel type are defined in terms of the source activity levels, A^{u}_{hijk} from equation (1), by:

$$A^{u}{}_{hik} = \sum_{j} A^{u}_{hijk} \quad (5)$$

$$A^{u}{}_{hk} = \sum_{i} A^{u}_{hik} \quad (6)$$

$$A^{u}{}_{k} = \sum_{h} A^{u}_{hk} \quad (7)$$

Where A^{u}_{hik} is the total activity level of mobile category i in sector h using fuel type k;A^{u}_{hk} is the total activity level of all categories in sector h using fuel type k; and A^{u}_{k} is the total activity level of all categories in all sectors using fuel type k.

In the following equations, activity levels taken directly from ABARE data are presented in bold type (for example $\boldsymbol{A^{m=1}_{2,2}}$ is ABARE's estimate of road transport ADO use).

The main adjustments made to ABARE energy consumption estimates allow for off-road, marine and military/diplomatic fuel use. Fuel use in the operations of the Australian Defence Forces is not separately reported by ABARE; nor is fuel use, by non-road and off-road sources such as marine pleasure craft, trail-bikes or lawn-mowers. Military transport fuel use in each year is estimated to be 0.06 per cent of the road automotive gasoline and consumption reported by ABARE for that year, 0.5 per cent of road ADO, 3.5 per cent of Avgas, 8.0 per cent of Avtur, 40 per cent of marine ADO, and 0.05 per cent of marine fuel oil consumption (based on Department of Defence [Martin, N.] and ABS 2006c). ABARE's figure for total road transport use of automotive gasoline is reduced by a further 3.13 per cent of total road automotive gasoline. This fuel is allocated to miscellaneous non-road and off-road uses: 2.39 per cent for marine pleasure craft, 0.1 per cent for unregistered motor vehicles, and 0.63 per cent for lawn-mowers. The percentages allocated to each of these use categories are presented in Table A.1.

In the following equations the factors in Table A.1 are referred to by the Australian New Zealand Standard Industrial Classification (ANZSIC) code and fuel type (k) and the capital letter referring to the fuel use activity. For example the fraction of ABARE's road transport ADO used in military vehicles is 51_2B.

Energy activity levels (m=1) are derived (in PJ) from ABARE data using the following equations.

Civil Aviation

Domestic Avgas Consumption is derived from the reported Avgas consumption ($\boldsymbol{A^1_{1,1,4}}$) by subtracting the military Avgas consumption ($A^1_{5,1,4}$).

$$A^1_{1,1,4} = \boldsymbol{A^1_{1,1,4}} - A^1_{5,1,4} \quad (8)$$

Domestic Avtur Consumption is derived from the reported Avtur consumption ($\boldsymbol{A^1_{1,1,5}}$) by subtracting the military Avtur consumption ($A^1_{5,1,5}$).

$$A^1_{1,1,5} = \boldsymbol{A^1_{1,1,5}} - A^1_{5,1,5} \quad (9)$$

International Avtur Consumption is equal to the reported International Avtur consumption ($\boldsymbol{A^1_{1,2,5}}$)

$$A^1_{1,2,5} = \boldsymbol{A^1_{1,2,5}} \quad (10)$$

Road Transportation

Automotive gasoline used by road transport is estimated to be the fraction 51_1A (Table A.1) of the consumption reported by ABARE. The remainder of automotive gasoline is used in lawn mowers, marine pleasure craft and off-road vehicles.

Military vehicles using automotive gasoline are assumed to have emission factors (in g/MJ) equivalent to those for gasoline light duty vehicles and those using ADO are assumed equivalent to heavy duty ADO trucks with moderate emission control (derived from OECD 1991).

$$A^1_{2,1} = \boldsymbol{A^1_{2,1}} \times 51_1A \quad (11)$$

Automotive diesel fuel used in road vehicles is derived from the reported ADO consumption ($\boldsymbol{A^1_{2,2}}$) by subtracting the ADO consumed in military land vehicles ($A^1_{5,2,2}$).

$$A^1_{2,2} = \boldsymbol{A^1_{2,2}} - A^1_{5,2,2} \quad (12)$$

Liquefied petroleum gas consumed in road vehicles is derived from the reported LPG consumption ($\boldsymbol{A^1_3}$) by subtracting the LPG consumed in industrial equipment ($A^1_{6,3,3}$).

$$A^1_{2,3} = \boldsymbol{A^1_3} - A^1_{6,3,3} \quad (13)$$

Natural gas consumed in road vehicles is equivalent to the consumption reported by ABARE ($\boldsymbol{A^1_{2,8}}$).

$$A^1_{2,8} = \boldsymbol{A^1_{2,8}} \quad (14)$$

Railway Transport

ADO, industrial diesel fuel and black coal consumed by railways in Australia are equivalent to the values reported by ABARE.

$$A^{1}_{3,2} = \mathbf{A^{1}_{3,2}} \quad (15)$$

$$A^{1}_{3,6} = \mathbf{A^{1}_{3,6}} \quad (16)$$

$$A^{1}_{3,9} = \mathbf{A^{1}_{3,9}} \quad (17)$$

Navigation

Domestic marine pleasure craft using automotive gasoline are estimated to consume the fraction 51_1C (Table A.1) of total gasoline consumed ($\mathbf{A^{1}_{2,1}}$) in road transport reported by ABARE.

$$A^{1}_{4,1,1,1} = \mathbf{A^{1}_{2,1}} \times 51_1 C \quad (18)$$

ADO consumed in domestic marine transportation is estimated to be the ADO consumed in domestic marine transportation by ABARE ($\mathbf{A^{1}_{4,1,2}}$) minus that consumed by military shipping ($A^{1}_{5,3,2}$).

$$A^{1}_{4,1,4,2} = \mathbf{A^{1}_{4,1,2}} - A^{1}_{5,3,2} \quad (19)$$

IDF consumed in domestic marine transportation is equivalent to the value reported by ABARE.

$$A^{1}_{4,1,4,6} = \mathbf{A^{1}_{4,1,6}} \quad (20)$$

Fuel oil consumed in domestic marine transportation is estimated as the values reported by ABARE ($\mathbf{A^{1}_{4,1,7}}$) minus the fuel oil consumed in military shipping ($A^{1}_{5,3,7}$).

$$A^{1}_{4,1,4,7} = \mathbf{A^{1}_{4,1,7}} - A^{1}_{5,3,7} \quad (21)$$

Natural gas and black coal consumed in domestic marine transportation are equivalent to the values reported by ABARE ($A^{1}_{4,1,8}$& $A^{1}_{4,1,,9}$).

$$A^{1}_{4,1,4,8} = \mathbf{A^{1}_{4,1,8}} \quad (22)$$

$$A^{1}_{4,1,4,9} = \mathbf{A^{1}_{4,1,9}} \quad (23)$$

ADO, IDF and natural gas consumed by international marine transportation are equivalent to the values reported by ABARE ($\boldsymbol{A^1}_{4,2,2}$, $\boldsymbol{A^1}_{4,2,6}$ & $\boldsymbol{A^1}_{4,2,7}$)

$$A^1_{4,2,2} = \boldsymbol{A^1}_{4,2,2} \quad (24)$$

$$A^1_{4,2,6} = \boldsymbol{A^1}_{4,2,6} \quad (25)$$

$$A^1_{4,2,7} = \boldsymbol{A^1}_{4,2,7} \quad (26)$$

Military Transport

Military avgas consumption is estimated to be the fraction 54_4B (Table A.1) of the ABARE avgas consumption ($\boldsymbol{A^1}_{1,4}$).

$$A^1_{5,1,4} = \boldsymbol{A^1}_{1,4} \times 54_4 B \quad (27)$$

Military avtur consumption is estimated to be the fraction 54_5B (Table A.1) of the ABARE avtur consumption ($\boldsymbol{A^1}_{1,5}$).

$$A^1_{5,1,5} = \boldsymbol{A^1}_{1,5} \times 54_5 B \quad (28)$$

Military gasoline consumption is estimated to be the fraction 51_1B (Table A.1) of the ABARE gasoline consumption ($\boldsymbol{A^1}_{2,1}$).

$$A^1_{5,2,1} = \boldsymbol{A^1}_{2,1} \times 51_1 B \quad (29)$$

Military land vehicle ADO consumption is estimated to be the fraction 51_2B (Table A.1) of the ABARE ADO consumption ($\boldsymbol{A^1}_{2,2}$).

$$A^1_{5,2,2} = \boldsymbol{A^1}_{2,2} \times 51_2 B \quad (30)$$

Military marine ADO consumption is estimated to be the fraction 53_2B (Table A.1) of the ABARE marine ADO consumption ($\boldsymbol{A^1}_{4,2}$).

$$A^1_{5,3,2} = \boldsymbol{A^1}_{4,2} \times 53_2 B \quad (31)$$

Military marine fuel oil consumption is estimated to be the fraction 53_7B (Table A.1) of the ABARE marine fuel oil consumption ($\boldsymbol{A^1}_{4,7}$).

$$A^1_{5,3,7} = \boldsymbol{A^1}_{4,7} \times 53_7 B \quad (32)$$

Other Mobile Sources

Recreational vehicles are assumed to consume 0.1% of total gasoline consumption reported by ABARE ($\boldsymbol{A^1}_{2,1}$).

$$A^1_{6,1,1} = \boldsymbol{A^1}_{2,1} \times 51_1 D \qquad (33)$$

Utility engines such as lawn mowers and chain saws are estimated to be the fraction 51_1E (Table A.1) of total gasoline consumption reported by ABARE ($\boldsymbol{A^1}_{2,1}$).

$$A^1_{6,4,1} = \boldsymbol{A^1}_{2,1} \times 51_1 E \qquad (34)$$

1.A.3a Civil Aviation

The estimation of carbon dioxide emissions from civil aviation is undertaken using a Tier 2 methodology and emission factors given in Table A.2. Non-carbon dioxide emissions from domestic civil aviation are estimated using a Tier 2 methodology. The methodology involves calculation of emissions as a function of the landing/takeoff cycles (LTO's) for domestic and international aircraft and requires data on the number of LTO cycles for aircraft; data on the Australian aviation capital stock or aviation fleet profile; and average emission factors by type of aircraft. Fuel consumption is calculated for the LTO modes and subtracted from the total fuel used for the domestic and international fleets to produce the fuel consumption for the cruise mode. Cruise emissions are then calculated as a function of fuel use. Emissions from international aviation are also estimated, but are excluded from national emission inventory aggregates by international agreement.

The Australian aviation fleet profile is developed using the Australian Aircraft Register which is available from the Civil Aviation Safety Authority. Emission factors for each aircraft type (IPCC 2006) are used to create weighted average LTO cycle emission factors for the domestic and international aviation fleets.

Data on the yearly avtur consumption for the domestic and international aircraft are available from ABARE. The data required for the total yearly LTO for the domestic and international aircraft are available from Avstats, Department of Transport and Regional Services.

Cruise emission factors are taken from IPCC (1997) (Table 5).

Table 4: Emission Factors by aircraft type

Aircraft type	CH_4	N_2O	NOx	CO	NMVOCs
DHC-8-100	0.00	0.02	1.51	2.24	0.00
DHC-8-200	0.00	0.02	1.51	2.24	0.00
A320	0.06	0.10	9.01	6.19	0.51
A330-200/300	0.13	0.20	35.57	16.20	1.15
BAE 146	0.14	0.00	4.07	11.18	1.27
B717	0.01	0.10	10.96	6.78	0.05
B727-200	0.81	0.10	11.97	27.16	7.32
B737-300/400/500	0.08	0.10	7.19	13.03	0.75
B737-700	0.07	0.10	9.12	8.00	0.78
B737-800	0.33	0.10	12.30	7.07	0.65
B767-200	0.10	0.10	23.76	14.80	2.99
B767-300	0.09	0.20	28.19	14.47	1.07
SAAB 340	0.00	0.02	1.51	2.24	0.00
SA227	0.00	0.02	1.51	2.24	0.00
SA226	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	0.14	0.10	5.63	8.88	1.23
EMB 110	0.06	0.01	0.30	2.97	0.58
EMB 120	0.00	0.02	1.51	2.24	0.00
Cessna 525	0.33	0.03	0.74	34.07	3.01
Beech 200	0.06	0.01	0.30	2.97	0.58
F27	0.03	0.02	1.82	2.33	0.26

Source: IPCC 2006

Table 5: Weighted average emissions factors per LTO

Category	CH_4 (kg)	N_2O (kg)	NOx (kg)	CO (kg)	NMVOC (kg)
Domestic Interstate Fleet	0.09	0.10	11.67	8.90	0.80
Regional Fleet	0.03	0.02	1.15	3.15	0.29
International Fleet	0.23	0.32	46.6	25.24	2.09

Source: DCC estimates, derived from CASA Civil Aircraft Register (2006) and IPCC (2006).

Table 6: Cruise emission factors

Category	kg of emissions/Mg of fuel				
	CH_4	N_2O	NOx	CO	NMVOC
Domestic and Regional Fleet	0	0.1	11	7	0.7
International Fleet	0	0.1	17	5	2.7

Source: IPCC (1997).

The weighted average LTO emission factors for the domestic commercial, regional and international categories are calculated based on the emission factors for individual aircraft types and the numbers of aircraft of each type within each aviation category. This approach results in higher estimated LTO emission factors for the international sector. The estimated weighted emission factors have been held constant throughout the time series 1990-2003, and are adjusted in line with changes in the aviation capital stock from 2004 onwards.

The estimated average emission factor for LTO cycles is weighted by the characteristics of the Australian aviation fleet and could be refined with data on the number of LTOs undertaken by each type of aircraft. Nonetheless, the implications for the uncertainty of the emission estimate introduced by this simplification is likely to be small, given the dispersed and varied nature of the aviation stock and the small contribution to national emissions of this emission source.

1.A.3.b Road Transportation

Like the aviation sector, the estimation of carbon dioxide emissions from the road transport sector is based on a Tier 2 method with emission factors given in Table A.2. The estimation of non-carbon dioxide emissions is based on a Tier 3 method, with the emission estimates dependent on the type of vehicle, the age of the vehicle capital stock, technology, operating mode (cold versus hot) and road type (urban versus non-urban).

The proportion of total consumption of each fuel (*k*), by each vehicle type (*i*) for the Road Transport Sector (*h*=2), has been calculated from vehicle stock data contained in ABS 2007a.

The annual total transport energy consumption by fuel type, $A^{u=1}{}_{2k}$ [from equations (11) to (14)], has been allocated to each vehicle category (i), using:

$$A^{u=1}{}_{2ik} = A^{u=1}{}_{2k} \times Q_{ik}$$

for k = 1,2,3,7,9 and i = 1 to 6 (35)

Where Q_{ik} is the proportion of fuel type k consumed by vehicle type i.

Vehicle distances travelled are calculated from the energy consumption levels (calculated from equation 35) using:

$$A^{u=2}{}_{2ik} = A^{u=1}{}_{2ik} \Big/ (R_{ik} \times D_k)$$

for k = 1,2,3,7, and 9 and i = 1 to 6 (36)

Where $A^{u=2}{}_{2ik}$ is the distance travelled (in Vehicle Kilometres Travelled) by vehicle type i, using fuel type k; and
R_{ik} is the average rate of fuel consumption (in l/km) for vehicle type i, using fuel type k.
D_k is the energy density of fuel type k (in MJ/l)

Carbon Dioxide Emissions from Road Transportation

The methodology is applied to each of the eight Australian States and Territories. Differences in emission estimates across the States principally reflect differences in fuel consumption and the impacts on non-CO_2 emission estimates of differentials in the age distribution of each State's vehicle fleet. National emissions are estimated as the sum of the State and Territory emissions.

1.A.3.bi-v Passenger, Light Commercial, Medium, Heavy Vehicles and Buses

Carbon dioxide emissions from light and heavy duty vehicle fuel sources have been estimated based on the quantity of fuel consumed by the CO_2 emission factor specific to that fuel and the proportion of that fuel which is completely oxidised.

$$E_{ijk} = A^{u=1}_{ijk} \text{ x } (F_k \text{ x } P_k) \qquad (43)$$

Where $F(l)_k$ is the CO_2 (l=1) emission factor (for fuel type k) applicable to complete oxidation of fuel carbon content;
P_k is the proportion of fuel that is completely oxidised upon combustion; and
A^u_{ijk} is the fuel consumed for vehicle type i with age band j and fuel type k (and where $u=1$ for fuel consumption in each Australian State)

For l = 1 and k = 1,2,3,7 and 9

The CO_2 emission factors and oxidation factors for each fuel are summarised in Table A.2.

For all vehicles besides motorcycles consuming automotive gasoline, ethanol, diesel and LPG non-CO_2 emissions for each age class are estimated based on vehicle kilometres travelled in each State or Territory; the profile and age of the vehicle capital stock in each State; the penetration of catalytic control technology; mode of operation and road type; and vehicle and fuel specific emission factors.

It is assumed that all light duty vehicles go through a cold start phase for each trip which is associated with higher emissions due to engine and catalyst temperatures that are below optimum. The number of cold starts is derived from total VKT and an average trip length of 10km (based on data cited in VicHealth (1999), QLD Transport (2001), and NSW EPA (2000)). A cold-start duration of 3km (as cited in IPCC 2006) is used to determine the total cold start VKT. This is subtracted from total VKT to derive an adjusted total VKT value.

Emission factors vary by road type (urban versus non-urban) to reflect the different driving conditions and engine operating profiles. Total adjusted VKT is further disaggregated into urban and non-urban VKT in each State. This allows for emissions estimates to be calculated according to driving and traffic-flow conditions.

Vehicles using automotive gasoline, ethanol, diesel and LPG are further classified by age of vehicle (using data contained in ABS 2006a). The divisions in the vehicle fleet enable differences in emissions control technology and differences in fuel efficiency across age classes to be factored into the emissions estimation. Vehicles manufactured and sold in Australia before 1976 are assumed to have no emissions control equipment. The 1976-1985 group uses a variety of non-catalytic control (such as exhaust gas recirculation) and the 1985-1997, 1998-2003, 2004-2005 and the post-2005 groups use catalytic control. The fractions of 2-way and 3-way catalyst equipped vehicles in these two age bands is presented in Table A.4. For diesel vehicles, this age band structure has been implemented to preserve internal consistency although no exhaust control distinction is made in the emission factors used.

Non-carbon dioxide exhaust emissions from vehicles have been calculated by the following form of equations:

$$E\,(l)_{ijk} = A_{adj}{}^{u=2}{}_{ijkmn} \times EF(l)_{ijkmn} \quad (44)$$

Where E is the emission of non-CO_2 gases (l = 2,3,4,5,6);

$A_{adj}{}^{u=2}$ is the adjusted vehicle kilometres travelled by vehicle type i and age band j using fuel type k, operating on road type m and operating mode n in each State or Territory;

$EF(l)_{ijk}$ is the exhaust emission factor for gas l from vehicle type i and age band j using fuel type k, operating on road type m and operating mode n in each State or Territory

for k = 1,2,3, and 9;

Cold start emissions are derived using equation 45:

$$Ecs_{ijk} = CS_{ijk} \times EFcs_{ijk} \quad (45)$$

Where Ecs_{ijk} are the cold start emissions for vehicle type i and age class j using fuel type k (k=1,2,3 and 9)

CS_{ijk} is the number of cold starts for vehicle type i and age class j, using fuel type k (k=1,2,3 and 9)

EF_{ijk} is the cold start emission factor (g/start) for vehicle type i and age class j, using fuel type k (k=1,2,3 and 9)

Emissions of non-CO_2 exhaust gases may increase as the vehicle ages due to the gradual wearing of components, poor maintenance, deactivation of catalyst materials, removal of emission control equipment, oxygen sensor failure, or modification of the engine.

Although the mechanisms through which emissions increase through the life of the vehicle are known, the available test data shows high variation in emissions in use, and little correlation of emissions with the distance the vehicle has travelled.

A study by EPA NSW, 1995 analysed the combined emission test databases of EPA NSW and EPA Victoria to determine deterioration rates and zero VKT (ie new vehicle) emissions for the two States' combined fleet. Despite the extreme scatter in these data, the general trend is for emissions to increase as the cumulative VKT increases.

Average emission factors for each vehicle age class may be calculated from the zero VKT emission levels (ZKL), the deterioration rates (DR) and the average accumulated VKT for that class. The deterioration factor is assumed to reach its limit at an accumulated average VKT of 150,000 km per vehicle. These equations are used to determine emission factors for the Australian fleet. The emission factors for a vehicle category have been determined from Equation 46.

Non-CO_2 emission factors are adjusted to account for vehicle age according to equation 46:

$$EF(l)_{jkm} = (ZKL_{ijk} + Dr_{ijk} \infty CumVKT_{ijm}) \qquad (46)$$

Where $EF(l)_{2ijkm}$ is the emission factor for gas l from each vehicle type i and age class j, using fuel type k (k=1,2,3) in each state or Territory;

ZKL_{ijk} is the zero kilometre level emissions of a gas l from vehicle type i and age class j

DR_{ijk} is the deterioration rate for vehicle type i and age class j

$CumVKT_{ijm}$ is the cumulative VKT for vehicle type i and age class j, in each state or Territory.

and where

$$CumVKT(l)_{ijkm} = \Sigma_{t=1-n} A^{u=2}{}_{ikm} \qquad (47)$$

Where $A^{u=2}{}_{ikm}$ is the average distance travelled (in km) by vehicle type i and age class j, using fuel type k (k=1,2,3 and 9) in each State or Territory summed over time.

Emission factors chosen were obtained from Australian sources where these were available and applicable to the vehicle fleet and its various modes of operation and fuel types. The use of disaggregated, country-specific emission factors is consistent with the IPCC tier-3 methodology.

Where country-specific emission factors were not available IPCC 2006 has been used. The choice of US versus European default factors has been dictated by the exhaust emission standards in the Australian Design Rules (ADR) applying to each particular vehicle vintage. Australian Design Rules have been harmonised with European Standards from 2004 in light duty vehicles and 1996 in heavy duty vehicles. Therefore the IPCC default factors used for post 2004 vintage light duty vehicles and post 1995 heavy duty vehicles are based on European data (COPERT IV). Prior to the harmonisation with European standards, US Federal Test Protocol standards were used as the basis for ADRs. Therefore USEPA default factors cited in IPCC 2006 are used for earlier vehicle vintages where required.

Australian design rules applied to Australia's vehicle fleet , their date of introduction and the European sources for these standards are outlined in tables 7 and 7a. The age-band structure of the motor vehicle emission model is based on the applicability of a given ADR to a given vehicle vintage.

Table 7: Australian petrol passenger car exhaust emission standards

Australian Standard	Year introduced	Source standard
ADR 79/00	2004	Euro 2
ADR 79/01	2006	Euro 3
ADR 79/02	2010	Euro 4

Source: Department of Transport and Regional Services

Table 7a: Australian heavy duty diesel exhaust emission standards

Australian Standard	Year introduced	Source standard
ADR 70/00	1996	Euro 1
ADR 80/00	2003	Euro 3
ADR 80/02	2008	Euro 4
ADR 80/03	2011	Euro 5

Source: Department of Transport and Regional Services

Emissions by age class and the sources of each emission factor are outlined in tables 8, 8a, 9 and 9a.

Emissions of CH_4 from vehicles are a function of the emission and combustion control technologies present as well as vehicle operating conditions. The main sources of country specific CH_4 emission factors for light-duty vehicles are outlined in table 7.
In some cases, CH_4 emission factors presented below have been derived from total hydrocarbon emission factors presented in the reports.

Table 8: Country specific CH_4 passenger vehicle emission factors

<table>
<tr><th rowspan="3">Vintage</th><th colspan="4">Carnovale[1] 1991</th><th>FORS[2] 1996</th><th>BTRE[3] 2002</th></tr>
<tr><th colspan="4">g/km</th><th rowspan="2">g/km</th><th rowspan="2">g/km</th></tr>
<tr><th>Congested</th><th>Residential</th><th>Arterial</th><th>Freeway</th></tr>
<tr><td>1990’s</td><td></td><td></td><td></td><td></td><td></td><td>0.06</td></tr>
<tr><td>1986–91</td><td></td><td></td><td></td><td></td><td>0.112</td><td>0.1</td></tr>
<tr><td>1985</td><td>0.0512</td><td>0.0816</td><td>0.032</td><td>0.04</td><td rowspan="2">0.144</td><td>0.15</td></tr>
<tr><td>1981–85</td><td>0.1254</td><td>0.1056</td><td>0.0822</td><td>0.0648</td><td></td></tr>
<tr><td>1976–80</td><td>0.1332</td><td></td><td></td><td>0.1116</td><td></td><td>0.21</td></tr>
</table>

Sources:
1. Carnovale (EPA VIC 1991) – derived from total hydrocarbon emission factors – assuming 6% of 1980 to 85 (ADR-27) vehicles HC emissions and 16% of post 1985 (ADR 37/00) vehicles HC emissions are CH_4
2. Federal Office of Road Safety (FORS) 1996 - – derived from total hydrocarbon emission factors – assuming 6% of 1980 to 85 (ADR-27) vehicles HC emissions and 16% of post 1985 (ADR 37/00) vehicles HC emissions are CH_4
3. Bureau of Transport and Regional Economics 2002 - based on NISE study 1 (FORS 1996), MAQS Emissions Inventory (NSWEPA 1995), NGGIC (1996), Air emissions inventory Port Phillip Bay Control Region (EPAV 1991)

The Federal Office of Road Safety (FORS) 1996 - *National In-Service Emissions study 1* was a comprehensive testing program which looked specifically at the emissions performance of Australia's passenger car fleet and the effects of tuning and emissions control deterioration. Tests were performed on a total of 640 passenger cars. Emissions measured were limited to hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NOx). Methane was not specifically identified in the study. However, it is possible to derive CH_4 emissions from HC emissions using standard assumptions about HC speciation.

Methane emission factors by road type are presented in Carnovale 1991. Approximately 10 Vehicles of vintage ranging from 1976 to post 85 were tested in this study. As with FORS 1996, methane emissions were not reported directly.

The Bureau of Transport and Regional Economics 2002 also provides CH_4 emission factors for a range vehicle age cohorts. These emission factors are based on those presented in Carnovale (1991) and FORS (1996).

As the emission factors cited in the above reports are most applicable to vehicles in the 2-way catalyst and pre catalyst technology categories, Carnovale (1991) emission factors were used for urban (congested) and non-urban (freeway) roads in the pre-1976 and 1976-1985 age cohorts and FORS (1996) emission factors were used for urban roads in the 1985-1997 (2 way catalyst) vehicle class.

For vehicles fitted with 3-way catalyst technology (1985-97, 1998-2005 and post-2005), US EPA emission factors have been chosen and adjusted for urban, non-urban roads (based on IPCC 2006 (COPERT IV) proportions). IPCC default cold start emission factors (US EPA) are used for all passenger and light commercial vehicle age and technology classes.

The emission factors used to estimate CH_4 emissions from the Australian petrol, diesel and LPG driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in table 9.

There are no country-specific CH_4 emission factors available for heavy-duty vehicles. These emission factors have been taken from USEPA 1989 and IPCC 2006 as indicated in table 9a. Methane emission factors for post-2005 vintage vehicles (Euro 3) have been derived based on the Euro 1 COPERT IV emission factor and an emission reduction factor over heavy Euro 1 diesel vehicles of 44% taken from COPERT 2007.

Table 9: CH4 emissions factors split by urban/non-urban road conditions and hot/cold operation for light duty vehicles

	Passenger Car						LCV					
	Urban						Urban					
	Hot		Cold		Non-urban		Hot		Cold		Non-urban	
fuel type	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
post 2005	0.003	COPERT IV	0.171	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)	0.003	COPERT IV	0.171	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)
2004-2005	0.017		0.249		0.011		0.017		0.249		0.011	
1998 - 2003	0.007	USEPA (as cited in IPCC 2006)	0.076	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.010	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.112	USEPA (as cited in IPCC 2006)	0.009	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.039		0.151		0.030		0.040		0.192		0.030	
1985 – 1997 (2-way cat)	0.112	FORS 1996	0.345		0.063		0.110		0.429		0.085	
1976 – 1985	0.125	Carnovale 1991	0.434		0.065	Carnovale 1991	0.140		0.487		0.087	
Pre 76	0.133		0.461		0.112		0.150		0.521		0.100	
LPG												
post 2005	0.080	COPERT IV	0.240	COPERT IV (converted to a per start EF)	0.025	COPERT IV (Highway)	0.080	Petrol LCV EF x Pass car LPG to petrol ratio	0.240	Petrol LCV EF x Pass car LPG to petrol ratio	0.025	Petrol LCV EF x Pass car LPG to petrol ratio
2004-2005	0.080		0.240		0.025		0.080		0.240		0.025	
1998 - 2003	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.024		0.096		0.011		0.024		0.096		0.011	
1985 – 1997 (2-way cat)	0.033		0.131		0.014		0.033		0.131		0.014	
1976 – 1985	0.031		0.125		0.014		0.031		0.125		0.014	
Pre 76	0.032		0.126		0.014		0.032		0.126		0.014	
ADO												
post 2005	0.003	COPERT IV	0.021	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)	0.003	COPERT IV	0.021	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)
2004-2005	0.007		0.018		0.002		0.007		0.018		0.002	
1998 - 2003	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.001		0.003		0.000		0.001		0.003		0.000	
1985 – 1997 (2-way cat)	0.001		0.004		0.001		0.001		0.004		0.001	
1976 – 1985	0.001		0.004		0.001		0.001		0.004		0.001	
Pre 76	0.001		0.004		0.001		0.001		0.004		0.001	
Ethanol[a]												
post 2005	0.037	USEPA (as cited in IPCC 2006) - mid-point of reported range	NA		0.049	Hot Ef x Petrol Non-urban to Hot Urban ratio	0.037	Passenger car EF x LCV to car ratio	NA		0.049	Ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004-2005	0.037				0.049		0.037				0.049	
1998 - 2003	0.037				0.025		0.053				0.048	
1985 – 1997 (3-way cat)	0.206	Post 97 EF x earlier petrol age class relativity			0.158		0.211				0.159	
1985 – 1997 (2-way cat)	0.592				0.331		0.581				0.449	
1976 – 1985	0.661				0.344		0.740				0.460	
Pre 76	0.703				0.592		0.793				0.529	

Sources (as indicated in table): FORS (1996), Carnovale (1991), and IPCC (2006)
a. Refers to raw ethanol. Cold start conditions assumed to last 3 km (IPCC 2006).

Table 9a: CH_4 emissions factors split by urban/non-urban road conditions and hot/cold operation for heavy duty vehicles

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source
Petrol												
Post 2002	0.078	COPERT IV (x EF reduction %)	0.062	COPERT IV (x EF reduction %)	0.078	COPERT IV (x EF reduction %)	0.062	COPERT IV (x EF reduction %)	0.078	COPERT IV (x EF reduction %)	0.062	COPERT IV (x EF reduction %)
1996 - 2002	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV
Pre 1996	0.140		0.110		0.140		0.110		0.140		0.110	
LPG												
Post 2002	0.123	USEPA 1989	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.123	USEPA 1989	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.067	USEPA 1989	0.029	Passenger car LPG COPERT IV non-urban to urban ratio
1996 - 2002	0.220		0.096		0.220		0.096		0.120		0.053	
Pre 1996	0.220		0.096		0.220		0.096		0.120		0.053	
ADO												
Post 2003	0.048	COPERT IV (x EF reduction %)	0.022	Hot urban EF x COPERT IV non-urban to urban ratio	0.098	COPERT IV (x EF reduction %)	0.045	Hot urban EF x COPERT IV non-urban to urban ratio	0.017	COPERT IV (x EF reduction %)	0.008	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.157	USEPA 1989	0.072		0.157	USEPA 1989	0.072		0.030	USEPA 1989	0.014	
Pre 1996	0.157		0.072		0.157		0.072		0.030		0.014	

Sources (as indicated in table): USEPA (1989) COPERT 2007 and IPCC (2006)

Emissions of N_2O from mobile combustion sources are not frequently measured. However, there is considerable evidence to suggest that the use of catalysts to control NOx and NMVOC actually increase the amount of N_2O emitted.

N_2O Emission factors for Australia's passenger vehicle fleet are based on CSIRO vehicle testing (Weeks et al, 1993) of vehicles of vintage up to 1993, fitted with a range of emissions control technology. Test data on vehicles not fitted with catalysts are used for the pre 1976 and the 1976-85 age groupings and a weighted average of the catalyst equipped emissions used for the 1985-1997 and 1998-2003 vehicle fleet. Emission factors for the 2004-2005 and post 2005 age class are taken from IPCC (2006). The emission factors in Weeks et al are comparable to those reported in the GPG and the US EPA and in COPERT IV and reflect the range of emissions control technology currently used in Australia to meet vehicle exhaust emissions standards.

The emission factors used to estimate N_2O emissions from the Australian petrol, ethanol diesel and LPG driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in table 10.

There are no country-specific N_2O emission factors available for heavy-duty vehicles. These emission factors have been taken from USEPA 1989 and IPCC 2006 as indicated in Table 10a.

Table 10: N_2O emissions factors split by urban/non-urban road conditions and hot/cold operation for light duty vehicles

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
fuel type	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
post 2005	0.003	COPERT IV	0.036	COPERT IV (converted to a per start EF)	0.002	COPERT IV (Highway)	0.005	COPERT IV	0.108	COPERT IV (converted to a per start EF)	0.005	COPERT IV (Highway)
2004-2005	0.011		0.072		0.003		0.022		0.186		0.022	
1998 - 2003	0.029	Weeks et al 1993	0.199	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.080	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.440	USEPA (as cited in IPCC 2006)	0.080	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.029		0.178		0.005		0.048		0.297		0.048	
1985 – 1997 (2-way cat)	0.011		0.106		0.002		0.015		0.138		0.015	
1976 – 1985	0.004		0.041		0.002		0.005		0.047		0.005	
Pre 76	0.003		0.036		0.002		0.003		0.041		0.002	
LPG												
post 2005	0.005	COPERT IV	0.027	COPERT IV (converted to a per start EF)	0.001	COPERT IV (Highway)	0.008	Petrol LCV EF x Pass car LPG to petrol ratio	0.081	Petrol LCV EF x Pass car LPG to petrol ratio	0.003	Petrol LCV EF x Pass car LPG to petrol ratio
2004-2005	0.013		0.069		0.002		0.026		0.178		0.018	
1998 - 2003	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.006		0.017		0.001		0.006		0.017		0.001	
1985 – 1997 (2-way cat)	0.003		0.008		0.002		0.003		0.008		0.002	
1976 – 1985	0.003		0.008		0.000		0.003		0.008		0.000	
Pre 76	0.002		0.005		0.000		0.002		0.005		0.000	
ADO												
post 2005	0.009	COPERT IV	0.045	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)	0.009	COPERT IV	0.045	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)
2004-2005	0.004		0.045		0.006		0.004		0.045		0.006	
1998 - 2003	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.001		0.003		0.002		0.001		0.003		0.002	
1985 – 1997 (2-way cat)	0.001		0.002		0.001		0.001		0.002		0.001	
1976 – 1985	0.001		0.002		0.000		0.001		0.002		0.000	
Pre 76	0.000		0.001		0.000		0.000		0.001		0.000	
Ethanol[a]												
post 2005	0.030	USEPA (as cited in IPCC 2006) - mid-point of reported range	NA		0.015	Post 97 hot Ef x Petrol Non-urban to Hot Urban ratio	0.049	Passenger car EF x LCV to car ratio	NA		0.049	ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004-2005	0.030				0.007		0.059				0.059	
1998 - 2003	0.030				0.025		0.082				0.082	
1985 – 1997 (3-way cat)	0.030	Post 97 EF x earlier petrol age class relativity			0.029		0.049				0.049	
1985 – 1997 (2-way cat)	0.012				0.011		0.015				0.015	
1976 – 1985	0.004				0.010		0.005				0.005	
Pre 76	0.003				0.010		0.003				0.002	

Sources (as indicated in table): WEEKS (1993) and IPCC (2006)

a. Refers to raw ethanol. Cold start conditions assumed to last 3 km (IPCCC 2006).

Table 10a: N_2O emissions factors split by urban/non-urban road conditions and hot/cold operation for heavy duty vehicles

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
Post 2002	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV
1996 - 2002	0.006		0.006		0.006		0.006		0.006		0.006	
Pre 1996	0.006		0.006		0.006		0.006		0.006		0.006	
LPG												
Post 2002	0.020	USEPA 1989	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.020	USEPA 1989	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.011	USEPA 1989	0.011	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.020		0.020		0.020		0.020		0.011		0.011	
Pre 1996	0.020		0.020		0.020		0.020		0.011		0.011	
ADO												
Post 2002	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.030		0.030		0.030		0.030		0.030		0.030	
Pre 1996	0.025	USEPA 1989	0.025		0.025	USEPA 1989	0.025		0.025	USEPA 1989	0.025	

Sources (as indicated in table): USEPA 1989 and IPCC 2006

1.A.3.b.v Evaporative Fuel Emissions

Road vehicles using automotive gasoline emit NMVOCs both from the exhaust and through evaporation. The evaporative NMVOC emissions include:

- **Running losses** resulting from evaporative emissions released during engine operation. Running losses occur when the capacity of the vapour control canister and purge system is exceeded by the vapour generation rate and are greatest at low average vehicle speeds. Running losses vary with the age and type of control system of the vehicle and the trip duration.
- **Hot soak losses** resulting from evaporation of fuel at the end of each trip. These emissions bear little relation to the VKT for an individual vehicle. A more realistic activity on which to base these emissions is the number of trips an average vehicle would make in a given time period.
- **Diurnal losses** resulting from vapour being expelled from fuel tanks due to ambient temperature rises. These emissions are strongly dependent on the Reid Vapour Pressure (RVP) of the fuel, the daily ambient temperature changes and where the vehicle is parked during the day. Emissions will vary significantly between identical vehicles in different geographical regions. Diurnal emissions only occur when the temperature is rising.
- **Resting losses** resulting through the permeation of fuel through rubber hoses or open bottom carbon canisters. Resting losses have often been included in measurements of hot soak, diurnal and running losses (USEPA, 1991).
- **Crankcase ventilation** resulted in NMVOCs being emitted from early model vehicles. Later model vehicles with positive crankcase ventilation (PCV) systems do not emit crankcase vapours (Haskew et.al., 1990). Crankcase ventilation emissions are relevant only for pre-1969 vehicles after which PCV was introduced. It is therefore unlikely that crankcase ventilation emissions will make a significant contribution to total evaporative emissions due to the small number of these vehicles in the current fleet.

Emission factors for evaporative emissions for each of the three passenger vehicle age classes have been estimated for average Australian temperatures and fuel properties and are presented in Table A.6.

1.A.3bvi Other Road Transportation

Fleet average emission factors for motorcycles are provided in Table A.3.

Non carbon dioxide emissions from off-road vehicles are determined on the basis of fuel consumed and the emission factors determined in the following sections. Emission factors for these categories are presented in Table A.3.

Off-road recreational vehicles consist largely of unregistered recreational and competition vehicles and 2-stroke motorcycles. Emission factors have been assumed to be equivalent to petrol fuelled passenger vehicles without emission controls.

Natural gas consumption for road transportation is subdivided into vehicle categories according to fleet composition data provided by the ABS. It is assumed that the ratio of average fuel consumption for each natural gas vehicle type to the fuel consumption rate for natural gas road vehicles is the same as the equivalent ratio for ADO fuelled vehicle types and ADO fuelled road vehicles. Thus, if the average ADO heavy truck consumes four times as much fuel per kilometre and travels five times as far per annum as the average ADO car, then the average natural gas heavy truck is assumed to have four times the fuel consumption and five times the annual utilisation of the average natural gas car.

Emission factors for N_2O (in g/km) for heavy duty road vehicles using natural gas (Table A.7) are assumed to be similar to those for heavy duty gasoline vehicles (OECD 1991).

1.A.3c Railways

Emissions are estimated using Tier 1 methods with carbon dioxide emission factors reported in Table A.2 and non-carbon dioxide emission factors reported in Table A.8.

Methodologies and emission factors for railway locomotives are taken from USEPA (1992). Locomotives are divided into three classes based on the scale of the railway companies' operations, and into line haul and yard locomotives for the three classes. There is insufficient data to differentiate by scale of operations, so only a single class is assumed. USEPA (1992) presents average emission factors for line haul locomotives in pounds of pollutant emitted per gallon of fuel consumed. USEPA (1992) also provides for the calculation of emission factors for a locomotive fleet which differs from the United States average fleet from which the emission factors were calculated. Given data on the composition and engine types in the local fleet, an average fleet emission factor has been calculated using the individual engine emission factors in USEPA (1992).

1.A.3d Navigation

Emissions are estimated using Tier 2 methods with carbon dioxide emission factors reported in Table A.2 and non-carbon dioxide emission factors reported in Table A.8.

Privately owned pleasure craft have a wide variety of engine configurations and power outputs. Outboard engines, particularly those with lower power, are predominantly two stroke petrol engines, whilst four stroke petrol outboards are only manufactured in larger power configurations.

Emission factors for inboard four stroke and diesel engines, outboard two- and four-stroke engines, and sailing boat auxiliary diesel engines are reported in USEPA (1991c, 1992), in kilograms per litre and grams per horsepower-hour.

A single emission factor is provided which is an average of the 2 and 4-stroke emission factors from USEPA (1991c, 1992).

Lloyd's Register, 1995 provides emission factors for low and medium speed diesel marine engines. These emission factors were based on steady state testing of 60 engines on 50 vessels and are considered to be the best available to date.

Bunker fuel purchased for shipping is generally centrifuged on the vessel to remove water and solid particles before it is used. The sludge produced from the centrifuge is disposed off-ship and contains approximately 35-55% hydrocarbon (F. Rostrom, Shipowners Association, personal communication). Due to this process a fraction of the fuel purchased is not actually combusted. This fraction is likely to be small but cannot be quantified at the present time due to a lack of information of the percentage of fuel which is disposed of as sludge.

These ADO emission factors are assumed to apply to IDF which has similar properties to ADO apart from its sulphur content.

Coal in marine use is assumed to have the same emission factors as in commercial coal fired boilers.

Natural gas in marine use is assumed to have the same emission factors as natural gas fired commercial boilers.

1.A.4 b Residential

Emissions are estimated using Tier 2 methods with carbon dioxide emission factors reported in Table A.2 and non-carbon dioxide emission factors reported in Table A.8.

Lawn Mowers

Lawn mowers are powered by small 2-stroke or 4-stroke engines. The emissions for each type of engine are substantially different, so in order to determine a representative average emission factor for the fuel used in lawn mowers it is necessary to determine the relative use of each type of engine.

The ratio of 2-stroke to 4-stroke mowers is approximately 60:40 the ratio is likely to move towards 4 stroke engines in future years (EPA NSW, 1995).

1.A.5b Military Land Vehicles

Emissions are estimated using Tier 2 methods with carbon dioxide emission factors reported in Table A.2 and non-carbon dioxide emission factors reported in Table A.8.

These may be classified as heavy duty diesel engines or as road diesel or petrol engines. An average diesel emission factor for ADO consumption in military land vehicles has been derived from the average of emission factors for heavy duty off-road and on-road vehicles.

Emission factors for petrol consumption in military vehicles are assumed to be equivalent to those for petrol fuelled light duty trucks.

Estimation of Other Mobile Sources

Farm, Forestry and Fishing Equipment

Emissions from mobile equipment used in the farm, forestry and fishing sectors are not included in the Transport (Mobile Sources) emissions inventory but in the Stationary Sources inventory. The non-CO_2 emission factors, however, are developed here.

Approximately 80% of the fuel used in agriculture is used in tractors and the remainder in self propelled equipment such as combine harvesters (H. Saddler, pers. comm. 1995).

USEPA (1991) provides emission factors for diesel tractors and other diesel equipment and weighted factors for a typical mix of equipment. Weighted average emission factors have been employed in deriving the default emission factors presented in Table A.5.

The only type of forestry equipment for which specific emission factors have been identified is log skidders. The forestry equipment emission factors adopted for the time being are the average of those for log skidders and for off-highway trucks presented by USEPA (1991).

USEPA (1991) gives average emission factors for fishing vessels based a variety of engine powers. If comprehensive data on the fishing fleet becomes available then emission factors may be weighted according to the fleet mix using USEPA (1991) data.

Industrial Equipment

Emissions from mobile equipment used in the manufacturing sector are not included in the Transport (Mobile Sources) emissions inventory but in the Stationary Sources inventory. The non-CO_2 emission factors, however, are developed here.

Industrial equipment includes a wide variety of vehicle types, such as earthmoving plant, dredging plant, mobile construction equipment and material handling equipment. ABARE's Fuel and Electricity Survey, however, indicates that fuel use by mobile sources in the manufacturing sector is largely dominated by materials handling. Earthmoving and bulk material handling equipment accounts for most of the diesel fuel used in mobile industrial equipment, and forklift trucks for nearly all of the LPG

As no specific emissions factors for LPG fuelled forklift trucks have been identified, the emission factors for LPG trucks have been adopted.

Average emission factors have been employed in deriving the default emission factors presented in Table A.5. Emission factors for diesel material handling equipment used in manufacturing are based on emission factors for a variety of equipment from USEPA (1991). The equipment types considered are wheeled and caterpillar tractors, wheeled dozers, scrapers, graders, loaders and off highway trucks.

Mining Equipment

Emissions from mobile equipment used in the mining sector are not included in the Transport (Mobile Sources) emissions inventory but in the Stationary Sources inventory. The non-CO_2 emission factors, however, are developed here.

Mining equipment consists of large trucks and loaders, particular those used in open cut operations. As no emissions factors specific to mining equipment have been identified, the emission factors adopted for the time are the average of those for off highway trucks and wheeled loaders (USEPA 1985).

Construction Equipment

Emissions from mobile equipment used in the construction sector are not included in the Transport (Mobile Sources) emissions inventory but in the Stationary Sources inventory. The non-CO_2 emission factors, however, are developed here.

The diesel vehicle emission factors for the construction sector are based on the average of the emission factors for eight types of equipment listed as construction equipment in USEPA (1991).

Glossary

Activity is in general the same as energy consumption.

Australian New Zealand Standard Industrial Classification (ANZSIC) – industry classification system of the Australian Bureau of Statistics.

Automotive diesel oil (ADO) is a middle distillate petroleum product used as a fuel in high-speed diesel engines. It is mostly consumed in the road and rail transport sectors and agriculture, mining and construction sectors. In future revisions of the transport methodology, consideration may need to be given to the impact of new ADO fuel specifications akin to the implementation of new Australian Design Rules for diesel vehicles.

Automotive gasoline (petrol) comprises light hydrocarbon oil for use in internal combustion engines excluding aircraft. It is treated to reach a sufficiently high octane number for use in motor vehicles. There are two types of petrol sold in Australia, leaded and unleaded. Leaded petrol, containing tetraethyl (TEL) and/or tetramethyl lead (TML) to enhance octane rating, is used in motor vehicles manufactured prior to 1986 and the unleaded form is used mainly in post-1985 vehicles. The precise composition varies with application, season and region (OECD 1992). Leaded fuel is a horizon fuel and in early 2002 was substituted with lead replacement fuel. In this workbook, no consideration has been given to the impact of LRP on the emission profile of a vehicle operating on this fuel. In future revisions of the transport methodology, consideration may need to be given to the impact of new petrol fuel specifications akin to the implementation of new Australian Design Rules for petrol vehicles.

Aviation gasoline (Avgas) is motor spirit specially prepared for aviation piston engines with an octane rating suited to the engine.

Aviation turbine fuel (avtur or jet fuel) is a middle distillate petroleum product used for aviation turbine engines.

Black coal for the purposes of this workbook comprises bituminous and sub-bituminous coals.

Emission factors are used to indicate the quantity of greenhouse gases emitted due to the combustion of a unit of fuel (measured in energy terms) or the quantity emitted per kilometre travelled.

Fuel oil covers all residual (heavy) fuel oils including those obtained by blending.

Fugitive emissions result from the leakage of chemical substances during various human activities. The main fugitive emissions from mobile sources occur through the evaporation of fuel from road vehicles.

Greenhouse gases for the purposes of this workbook include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorocarbon (FC) species. In addition the photochemically important gases non-methane volatile organic compounds (NMVOC), oxides of nitrogen (NO_x), carbon monoxide (CO) and sulphur dioxide (SO_2) are also considered. NMVOC, NOx, CO, and SO_{22} are not direct greenhouse gases. However, they contribute indirectly to the greenhouse effect by influencing the rate at which ozone and other greenhouse gases are produced and destroyed in the atmosphere.

Gross calorific value (GCV) is the quantity of heat released by unit quantity of fuel, when it is burned completely with oxygen, and the products of combustion are returned to liquid water at ambient temperature (101 kPa and 25^{o}C). GCV is measured per unit mass or unit volume. GCV is also known as higher heating value (HHV). GCV is the basis for Australian National Energy Statistics.

Industrial diesel fuel (IDF) is a petroleum product primarily consumed in the rail and marine transport sectors.

Liquefied petroleum gas (LPG) is a light hydrocarbon fraction of the paraffin series. It occurs naturally, associated with crude oil and natural gas in many oil and gas deposits, and is also produced in the course of petroleum refinery processes. LPG consists of propane (C_3H_8) and butane (C_4H_{10}) or a mixture. In Australia, LPG as marketed contains more propane than butane. LPG is used in a variety of sectors, such as for feedstocks in the chemical industry, fuel in motor vehicles and for heating and cooking purposes.

Mobile sources are sources of greenhouse gas emissions associated with mobile fuel combustion activities, regardless of the sector or industry for which the activity is undertaken. The following source categories are included in this workbook:

Civil Aviation includes all domestic and international aviation activities.

DomesticCivil aviation consists of commercial airline and general aviation (such as private, agricultural commuter and charter) services, for both freight and passenger movements.

International aviation includes international air freight and passenger movements accomplished using fuel uplifted in Australia.

Road transportation includes all on-road and off-road activity (on-road and off-road) by vehicles registered for road use (with a motor vehicle registration authority), except vehicles belonging to the Australian Defence Forces. Emissions by military vehicles and vehicles used exclusively for off-road purposes (such as competition motorcycles) are accounted for in other source categories below. The road transport sector is sub-divided into categories based on the vehicle definitions contained in Australian Design Rules (ADRs) For Motor Vehicles and Trailers (FORS 1989).

Passenger cars relate to all passenger vehicles which carry less than 10 passengers (including the driver). These consist of cars, station wagons, taxis, minibuses, four-wheel drive passenger vehicles and forward control passenger vehicles.

Petrol fuelled cars are subdivided into the following age bands (based on year of manufacture): pre-1976, 1976-1985 (comprising 1976-1980 and 1981-1985), 1986-1997 (comprising 1986-1988 and 1989-1997), and post-1997.

Light commercial vehicles are trucks and light commercial vehicles designed to carry goods and not exceeding 3.5 tonnes gross vehicle mass. These include utilities, panel vans, cab chassis and forward control load carrying vehicles. The equipment carried on special purpose vehicles having little freight carrying capacity (such as ambulances, fire trucks and mobile cranes) are regarded as being equivalent to goods vehicles for the purposes of vehicle definitions (FORS 1989).

Medium duty trucks are goods vehicles (including rigid trucks, articulated trucks and special purpose vehicles) with gross vehicle mass exceeding 3.5 tonnes but not exceeding 12.0 tonnes.

Heavy duty trucks are goods vehicles (rigid trucks, articulated trucks and special purpose vehicles) exceeding 12.0 tonnes gross vehicle mass.

Special purpose vehicles are vehicles having little freight carrying capacity (such as ambulances, fire trucks, and mobile cranes) and are regarded as being equivalent to goods vehicles for the purpose of vehicle classifications (FORS, 1989).

Buses are passenger vehicles with 10 or more seats, including that of the driver.

Motorcycles include all 2-wheeled and 3-wheeled motor vehicles.

Railway transport includes non-electric railway services for both passenger and freight movement. Since this Workbook deals solely with mobile combustion engines, emissions due to the generation of electricity for electric railways, are not included. Emission factors for electricity generation appear in the *Workbook for Fuel Combustion Activities (Stationary Sources)* 1.1.

Navigation includes all domestic and international maritime activity.

Domestic marine transportation consists of coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements.

International marine transportation includes passenger and freight movement by sea-going ships (of all flags) accomplished using marine bunker fuel purchased in Australia.

Military transport includes all activity by military land vehicles, aircraft and ships.

Other mobile sources covered in this Workbook include unregistered recreational or competition vehicles such as trail bikes and racing cars and miscellaneous mobile utility engines such as lawn-mowers and chain-saws. Emissions from farm and forestry equipment such as tractors and harvesters, and from equipment such as forklifts, bulldozers and quarry trucks used by the manufacturing, construction and mining sectors, are covered in *Australian Methodology for Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Stationary Sources),* 2006, Canberra.

Natural gas consists primarily of methane (around 90 per cent, with traces of other gaseous hydrocarbons, as well as nitrogen and carbon dioxide) occurring naturally in underground deposits. Production is measured after processing to extract heavier hydrocarbons (comprising LPG and condensate) and impurities, such as sulphur containing compounds and carbon dioxide. As a transport fuel, it is generally used in compressed or liquefied form.

Net calorific value (NCV) is the gross calorific value of a fuel less the heat of vaporisation (at 25˚C and constant volume) of the water present in the fuel and that formed during combustion. NCV is also known as lower heating value (LHV). The International Energy Agency (IEA) generally reports energy data in terms of NCV, whereas Australian National Energy Statistics are generally reported in GCVs. The IEA assumes that lower heating values are 5 per cent lower than higher heating values for oil and coal, and 10 per cent lower for natural gas (OECD 1991).

Oxidation, in the sense used here, is the process by which fuel is consumed by burning with oxygen.

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Appendix A. Emission Factors

Table A.1: Factors used to allocate ABARE fuel consumption to unlisted categories

ASIC category fuel consumption reported by ABARE		A General use	B Military	C Small marine craft	D Off-road vehicles	E Utility engines
51	Road transport automotive gasoline (51_1)[a]	96.81%	0.06%	2.39%	0.1%	0.63%
51	Road transport ADO (51_2)	99.5%	0.5%			
53	Water transport ADO (53_2)	60%	40%			
53	Water transport fuel oil (53_7)	99.95%	0.05%			
54	Air transport aviation gasoline (54_4)	96.5%	3.5%			
54	Air transport aviation turbine fuel (54_5)	92%	8%			

Source: (a) ABS (2006)

Table A.2: CO_2 Emission factors and liquid fuel energy densities by fuel type

Fuel Type	k	Proportion of Fuel Oxidised[a] (P_k)	CO_2 Emission Factor[a,b] ($F^1{}_k$) (g/MJ)	Energy Densityc (D_k) (MJ/L)
Automotive Gasoline	1	0.99	67.4	34.2
Automotive Diesel Oil	2	0.99	69.9	38.6
Liquefied Petroleum Gas	3	0.99	60.2	26.2
Aviation Gasoline	4	0.99	67.0	33.1
Aviation Turbine Fuel	5	0.99	69.6	36.8
Industrial Diesel Fuel	6	0.99	69.9	39.6
Fuel Oil	7	0.99	73.6	39.7
Natural Gas	8	1.00	51.4	39.3 MJ/m^3
Black Coal	9	0.99	90.0	N/A

N/A not applicable
Notes: Values are expressed in GCV terms
Figures for automotive gasoline refer to both leaded and unleaded forms

Sources:
a. NGGIC (1994a)
b. GHD 2006.
c. ABARE 2005.

Table A.3: Road category non-carbon dioxide emission factors

Source category			Emission factor (g/km)				
Vehicle type	Fuel type	Age band	CH_4 [a]	N_2O [c]	NOx [b,d]	CO [b,d]	NMVOC [b,d]
Passenger Cars [d]	Petrol	*Post 97*	See Table 9	See Table 10	0.225	0.869	0.077
		1985–1997 (3-way cat)			0.450	3.850	0.294
		1985–1997 (2-way cat)			0.930	5.460	0.260
		1976–1985			1.400	14.900	1.419
		Pre 76			2.460	24.000	2.275
	ADO	*Post 97*			0.250	0.116	0.062
		1985–1997 (3-way cat)			0.500	0.515	0.237
		1985–1997 (2-way cat)			1.034	0.731	0.210
		1976–1985			1.556	1.994	1.144
		Pre 76			2.734	3.212	1.833
	LPG	*Post 97*			0.472	2.327	0.199
		1985–1997 (3-way cat)			0.942	10.305	0.755
		1985–1997 (2-way cat)			1.947	14.614	0.669
		1976–1985			2.931	39.881	3.647
		Pre 76			5.150	64.238	5.846
Light Commercial Vehicles [d]	Petrol	*Post 97*			0.459	1.516	0.236
		1985–1997 (3-way cat)			0.917	6.712	0.894
		1985–1997 (2-way cat)			1.895	9.519	0.791
		1976–1985			2.853	25.977	4.314
		Pre 76			5.014	41.842	6.914
	ADO	*Post 97*			0.250	0.116	0.062
		1985–1997 (3-way cat)			0.500	0.515	0.237
		1985–1997 (2-way cat)			1.034	0.731	0.210
		1976–1985			1.556	1.994	1.144
		Pre 76			2.734	3.212	1.833
	LPG	*Post 97*			0.472	2.327	0.199
		1985–1997 (3-way cat)			0.942	10.305	0.755
		1985–1997 (2-way cat)			1.947	14.614	0.669
		1976–1985			2.931	22.875	3.647
		Pre 76			5.150	36.846	5.846

Source category			Emission factor (g/km)				
Vehicle type	Fuel type	Age band	CH_4 [a]	N_2O [c]	NOx [b,d]	CO [b,d]	NMVOC [b,d]
Medium Trucks	Petrol	*Post 02*	See Table 9a	See Table 10a	2.524	10.871	1.043
		1996–2002			2.524	10.871	1.043
		Pre 96			2.524	10.871	1.043
	ADO	*Post 02*			5.200	6.438	1.152
		1996–2002			5.200	6.438	1.152
		Pre 96			5.200	6.438	1.152
	LPG	*Post 02*			4.830	24.000	4.210
		1996–2002			4.830	24.000	4.210
		Pre 96			4.830	24.000	4.210
Heavy Trucks	Petrol	*Post 02*			2.524	10.871	1.043
		1996–2002			2.524	10.871	1.043
		Pre 96			2.524	10.871	1.043
	ADO	*Post 02*			5.200	6.438	1.152
		1996–2002			5.200	6.438	1.152
		Pre 96			5.200	6.438	1.152
	LPG	*Post 02*			4.830	24.000	4.210
		1996–2002			4.830	24.000	4.210
		Pre 96			4.830	24.000	4.210
Buses	Petrol	*Post 02*			3.910	48.610	3.470
		1996–2002			3.910	48.610	3.470
		Pre 96			3.910	48.610	3.470
	ADO	*Post 02*			4.900	2.880	1.560
		1996–2002			4.900	2.880	1.560
		Pre 96			4.900	2.880	1.560
	LPG	*Post 02*			2.760	24.000	2.410
		1996–2002			2.760	24.000	2.410
		Pre 96			2.760	24.000	2.410
Motorcycles	Petrol		0.150	0.002	0.210	19.270	4.580

Sources: a Hoekman (1992)
b Carnovale (1991)
c Weeks (1993)
d IPCC (2006)

Table A.4: Passenger and light commercial vehicle emission factor deterioration rates for petrol, diesel and LPG

Passenger vehicle age class	CH_4 g/km/VKT	CO g/km/VKT	NO_x g/km/VKT	NMVOC g/km/VKT
Post 2005[b]	8.43E-07	7.82E-05	8.91E-06	4.42E-06
2004-2005[b]	8.43E-07	7.82E-05	8.91E-06	4.42E-06
1998-2003[b]	8.43E-07	7.82E-05	8.91E-06	4.42E-06
1985-1997[a]	1.49E-06	1.57E-04	7.81E-06	7.83E-06
1985-1997[b]	8.43E-07	7.82E-05	8.91E-06	4.42E-06
1976 - 1985	4.76E-07	1.27E-04	6.48E-06	7.45E-06
Pre 1976	6.35E-07	1.45E-04	0.00E+00	9.95E-06

Source NSWEPA 1995
a 2-way catalyst
b 3-way catalyst

Table A.5: Catalyst Type Penetration

Year[a]	Fraction 2-way catalysts	Fraction 3-way catalysts
1988	50%	50%
1989	40%	60%
1990	30%	70%
1991	20%	80%
1992	20%	80%
1993	20%	80%
1994	20%	80%
1995-1997	20%	80%
Post 1997	0%	100%

Sources: Personal Communication W.R. King, FCAI, 1994 for years up to 1994, EPAV for 1995 to 2006.

Table A.6: Evaporative emission factors for road vehicles using automotive gasoline

Vehicle type (*i*, *j*) for sector *h*=2 and fuel type *k*=1	Emission Factor (g/km)	
	Hot soak and diurnal emissions[a] (FH*ij*)	Running losses[b] (FR*ij*)
Passenger Cars[c]		
Post 1985	0.38	0.9
1976 - 1985	0.96	0.9
Pre 1976	1.92	0.9
Light Trucks (i=2)	1.13	0.19
Medium Trucks (i=3)	2.24	0.26
Heavy Trucks (i=4)	2.75	0.29
Buses (i=5)	2.24	0.20
Motorcycles (i=6)	0.76	0.0

Sources: a. Carnovale et al. (1991), where pre-1970 cars (within car age class j=4) exhibit crankcase losses as well as hot soak and diurnal emissions;b. BTCE estimates based on OECD (1991); c.Calculated using methodology in Appendix B with an RVP of 11.0 psi

Table A.7: Non-CO_2 emission factors for natural gas road vehicles

Vehicle type(*i*) for sector *h*=2 and fuel type *k*=8	Emission factor[a] ($F(l)^{u=2}_{2ij8}$) (g/km)				
	CH_4 (*l*=2)	N_2O (*l*=3)	NO_x (*l*=4)	CO (*l*=5)	NMVOC (*l*=6)
Passenger Cars (*i*=1)	0.949	0.00364	0.691	0.400	0.0727
Light Trucks (*i*=2)	0.966	0.00370	0.703	0.407	0.0740
Medium Trucks (*i*=3)	0.828	0.00820	9.83	1.64	0.0820
Heavy Trucks (*i*=4)	1.68	0.0166	20.0	3.33	0.166
Buses (*i*=5)	1.45	0.0143	17.2	2.86	0.143

a. Derived from Equation (3) using data from Tables A.2, OECD (1991) and DeMaria (1992).

Table A.8: Non-CO_2 emission factors for non-road sources

Transport mode	CH4	N2O	NOx	CO	NMVOC
	(g/MJ)				
Rail transport [a]					
ADO	0.003	0.002	1.53	0.202	0.071
IDF	0.003	0.002	1.53	0.202	0.071
Coal	0.032	0.001	0.19	0.22	0.26
Marine transport [b]					
Domestic					
Petrol					
Small Craft	0.36	0.0009	0.254	20.3	3.24
ADO					
Ferries	0.004	0.002	1.105	0.246	0.075
Fishing	0.004	0.002	1.105	0.246	0.075
Shipping	0.007	0.002	1.58	0.163	0.046
IDF	0.007	0.002	1.58	0.163	0.046
Fuel Oil	0.003	0.002	2	0.044	0.063
NG	0.243	0.001	0.243	0.095	0.029
Coal	0.032	0.001	0.19	0.22	0.26
International					
ADO	0.007	0.002	1.58	0.163	0.046
IDF	0.007	0.002	1.58	0.163	0.046
Fuel Oil	0.003	0.002	2	0.044	0.063
Military Transport					
Petrol	0.026	0.0009	0.418	4.24	0.67
ADO					
Land	0.01	0.002	0.86	0.6	0.124
Water	0.007	0.002	1.58	0.163	0.046
Avtur Air	0.0005	0.0022	0.2335	0.1744	0.0176
Other mobile sources					
Recreational vehicles					
Petrol	0.03	0.0009	0.37	7	1.08
Industrial equipment					
ADO	0.0057	0.002	1.006	0.39	0.108
LPG	0.022	0.001	0.437	5.465	0.409
Farm equipment					
ADO	0.01	0.002	1.36	0.541	0.189
Tractors	0.0096	0.002	1.362	0.543	0.183
Non-tractors	0.011	0.002	1.351	0.531	0.21
Utility engines					
Petrol	0.38	0.0009	0.087	13	3.45

Sources: IPCC (1997), a USEPA (1992) b Lloyds Register 1995 and previous issues). F.Carnovale personal communication, 1995.

Appendix B. Estimation of Evaporative Fuel Emissions

The emission factors presented in this workbook represent national average temperatures and fuel properties. Where more detailed analysis is required (for example on a state by state basis) and the relevant data is available the following techniques may be used to estimate evaporative fuel emissions on a more detailed basis.

Running Losses

No measurement of running losses have been undertaken in Australia at this time and measurements of running losses in the US show significant variation in the magnitude of running losses contribution to total evaporative emissions.

Running losses have been shown to increase with increasing ambient temperature, fuel RVP and decreasing vehicle speed due to the reduced canister purging efficiency at low vehicle speeds. They are also related to trip length which influences the state of carbon canister purging (USEPA, 1991).

Running losses originate from a number of sources including the vent of the vapour canister, the fuel filler cap and the separate fuel tank pressure relief valve (if present) (Brooks et.al., 1992).

According to the USEPA (Federal Register, 1990, 1993), no readily identifiable vehicle characteristics such as fuel supply system or vehicle make and model have been found to influence the magnitude of running losses. Emissions appear to be dependent on complex combinations of programmed purge rates under a wide range of driving conditions.

Due to the absence of any Australian data on running losses and the conflicting results of measurements in the USA, it is inappropriate to disaggregate running loss emissions below a nationwide fleet average at this point in time.

Most US test data for running loss emissions has been determined using standard test fuel with an RVP of 9.0 psi, which is well below that of typical fuel sold in Australia. However, limited testing on late model vehicles using 11.5 psi RVP fuel (which is more typical of fuel on sale in Australia) have indicated running losses of the order of 1.1 g/km (Federal Register, 1990, 1993), compared to 0.2 g/km for 9.0 psi RVP fuel. The testing conducted on running loss emissions shows that emissions increase with fuel RVP and with increasing ambient temperature, but the limited number of measurements is insufficient to allow any reliable correlation between these variables. For these reasons a fleet average running loss of 0.9 g/km has been adopted for all ambient temperatures and for all vehicles. This value is based on 11.5 psi RVP fuel at three different temperatures 2-20^{o}C, 15-30^{o}C, and 20-35^{o}C reported by Black (1989), Halberstadt (1990) and Federal Register (1990, 1993).

Running losses may be calculated using Equation B-1

$$EVAP^{RU}_{hij} = \frac{RU \times VKT_{Total}}{10^9} \qquad \text{(B-1)}$$

Where $EVAP^{RU}_{hij}$ = total running loss (Gg)
RU = running loss emission factor (g/km)
VKT_{Total} = total VKT by passenger vehicles

The estimation of running losses should be re-examined as more data becomes available regarding the influence of control technology, RVP and ambient temperature.

Diurnal Losses

Diurnal losses occur because of the increase in liquid fuel volume and fuel vapour pressure as ambient temperature, and hence fuel tank temperature rises during the day. These two factors increase the pressure in the tank and cause the saturated petrol vapour to be expelled. The quantity of vapour expelled from an uncontrolled automotive petrol tank has been correlated with the RVP of the fuel and the diurnal temperature rise by Reddy (1989), as follows:

$$FVG_{mn} = A_e{}^{B(RVP)}\left(e^{CT_2} - e^{CT_1}\right) \times VS \times 0.264 \qquad \text{(B-2)}$$

Where A = 0.00817 (a constant)
B = 0.2357 (a constant)
C = 0.0409 (a constant)
T_1 & T_2 are the initial and final tank temperatures (∞F), and,
RVP = Fuel Reid Vapour Pressure (psi)
VS = fuel tank vapour space (litres) (assumed equal to 40 L, average fill level of 60% (USEPA, 1995) and typical fuel system volume of 66 L)
FVG_{mn} = fuel vapour generation rate (g/day)

Equation B-2 calculates the uncontrolled emission for one daily temperature cycle. To determine total annual emissions the value calculated here must be multiplied by the number of days per period.

Modern vehicles are fitted with equipment that controls diurnal evaporative losses. The uncontrolled emission estimates require adjustment for the control efficiency of the various types of control equipment.

The total diurnal emissions during a given season in a geographical region (or a whole country) may be estimated from the average seasonal diurnal temperature variation in that region, the relevant RVP of the fuel used in the region and the number of vehicles in the region.

$$EVAP^{D}_{hij} = \sum_{m=1}^{8} \sum_{n=1}^{4} \sum_{i=1}^{5} FVG_{mn} \times N_{imn} \times (1 - CEF_{i}) \times Days_{n} \times 10^{-9} \qquad \text{(B-3)}$$

Where $EVAP^{D}_{hij}$ = total diurnal loss (Gg)
FVG_{mn} = Fuel Vapour Generation rate(g/day) for state *m* in season *n*
N_{imn} = number of vehicles in class *i* in state *m* and season *n*
CEF_{i} = vapour control efficiency of vehicles in class *i*
$Days_{n}$ = number of days in season

Hot Soak Losses

Hot soak losses have been found to be much less sensitive to temperature than are diurnal emissions but are highly dependant on the recent driving history and the way in which this affects the state of the carbon canister. A vehicle which has an incompletely purged canister at the time the vehicle is stopped may have substantially higher hot soak losses because of vapour breakthrough if the canister carbon becomes saturated (Stump et.al., 1992 a & b). The level of hot soak emissions will also vary according to the engine technology. Carburetted vehicles will have higher hot soak emissions than throttle body injected and port injected vehicles.

Hot soak losses may be expressed as a fraction of diurnal emissions based on data from Stump et.al. (1992 a & b). The diurnal to hot soak loss ratio was found to be between 2 and 3, depending on the fuel supply system and the ambient temperature. The diurnal to hot soak ratios applicable to vehicle age classes are presented in Table B.1.

Table B.1: Diurnal to hot soak emission ratios

Vehicle Vintage	Dominant Fuel Supply System	Diurnal/Hot Soak Emission Ratio R^{DH}
Pre 1976	Carburetted	2
1976-1985	Carburetted	2
Post 1986	Injection	3

The hot soak losses for the fleet may be calculated using the diurnal losses calculated above, the diurnal to hot soak ratios, and equation B-4:

$$EVAP^{HS}_{hij} = \sum_{m=1}^{6} \sum_{n=1}^{4} \sum_{i=1}^{5} \left(FVG_{mn} \times N_{imn} \times (1 - CEF_{i}) \big/ R^{DH}_{imn} \right) \times Days_{n} \qquad \text{(B-4)}$$

Where $EVAP^{HS}_{hij}$ = Hot soak emissions from the fleet
R^{DH}_{imn} = Ratio of diurnal to hot soak emissions from Table B.1.

Resting Losses

Resting losses have not been explicitly measured in Australia to date and have only recently been included separately in the USEPA MOBILE vehicle emission model (USEPA, 1991). Resting losses are a function of temperature and whether an open bottom or closed bottom canister is used in the vehicle's evaporative emission control system. Resting losses for recent model US vehicles have been measured by Haskew et.al. (1990) and it was found that vehicles with open bottom canisters had resting losses five times those of vehicles with closed bottom canisters.

In the absence of Australian data on resting losses, these emissions are estimated using a simple weighted average of emissions for open and closed bottom canisters based on data from Haskew et.al. (1990), as follows:

$$EVAP^{RE} = \left(REL^{CB} \times X^{CB} + REL^{OB} \times X^{OB}\right) \times N \times 365 \times 10^{-9} \qquad \text{(B-5)}$$

Where $EVAP^{RE}$ = Resting loss emissions for the passenger vehicle fleet (Gg/year)
REL^{CB} = resting loss emissions for vehicles with closed bottom canisters (1.2 g/day)
REL^{OB} = resting loss emissions for vehicles with open bottom canisters (8.4 g/day)
X^{CB} = fraction of passenger vehicles with closed bottom canisters
X^{OB} = fraction of passenger vehicles with open bottom canisters
N = number of vehicles in the fleet

Crankcase Losses

Crankcase losses are only relevant for pre 1969 (Carnovale et.al., 1991) vehicles, and because of the reducing number and distance travelled by these vehicles the emissions from this source are assumed to be insignificant.

Total Evaporative NMVOC Emissions

Total NMVOC evaporative emissions are determined for the road vehicle fleet using Equation B-6.

$$E(6)_{2ijl} = EVAP^{RE} + EVAP^{RU} + EVAP^{HS} + EVAP^{D} \qquad \text{(B-6)}$$