

**Investigation of the Greenhouse Impacts of Different
Transport Modes in Australian Cities**

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SUMMARY

One way to reduce greenhouse gas emissions from transport is to encourage a shift of travel patterns from a mode of transport that emits a large amount of greenhouse gases (such as the car) to modes that produce smaller emissions (trams, trains, buses) or near zero emissions (walking and cycling). To discover the effects of such a shift, it is first necessary to arrive at a comparative assessment of greenhouse emissions from different motorized modes.

The key metric here is greenhouse emissions per passenger kilometre traveled for each mode of transport¹. This will vary, however, depending on two factors: the greenhouse efficiency of the energy source and the occupancy rate of the vehicles. The energy source may be a motor converting fuel into motive power on the vehicle, as in the case of petrol or diesel cars and buses, or an electric motor on the vehicle drawing energy (converted to electricity) from a remote source such as a coal fired power station (electric trains, trams and buses). For petrol and diesel vehicles their fuel efficiency is a key factor, and for electric vehicles powered from remote sources, the rate at which energy in fuel is converted to motive power is a key factor (conversion factor). In Victoria all motorized modes of transport at present ultimately depend on combustion of fossil fuels (coal, diesel oil, LPG, or petrol) that emit greenhouse gases, mostly carbon dioxide, CO₂. In future the amount of greenhouse gas emitted in the course of combustion to produce energy may change. The occupancy rate of vehicles may also change. But, as a base line, it is important to know what the situation is at present.

The objectives of this study are therefore:

1. To find out, as close as possible to the current year under current conditions, the greenhouse emissions (CO₂e) per passenger kilometre traveled for different modes of motorized transport in the Melbourne metropolitan area.
2. To define 'greenhouse emissions' and conduct a thorough search of relevant data bases to determine the total level of greenhouse gas (GHG) emissions (per capita and per vehicle) for each mode of transport in Melbourne and, for comparative purposes, with the other Australian metropolitan cities.
3. To investigate a variety of sources in order to discover passenger kilometres traveled per mode of transport in order to yield emissions per passenger kilometre traveled per mode.
4. To consider trends, issues and potential changes affecting GHG emissions from transport.

The assessment of greenhouse emissions involves considerable unavoidable complexity, and in this First Report we try to unravel and explain this complexity. We review four data sets — from the Apelbaum Consulting Group 2006, the Australian Greenhouse Office 2006, the BTRE 2002 and 2003, and Kenworthy and Laube 1999 — assessing their capacity to record the transport sector's GHG emissions in Australia. Based on a set of criteria, the four data sets were measured against each other for comprehensiveness (including key factors as the transport modes included in the study, the data provided at the city level, and the years covered). The BTRE 2002 report was identified as the most comprehensive report generating figures on GHG emissions per mode of transport for each capital city in Australia, as well as population figures over a period from 1990 to 2000. Additionally, the BTRE also provided forecast scenarios for GHG emissions per mode, population and GDP for the years 2001 to 2020.

In this First Report the focus is on available data sets and on the comparative data they provide for Australian capital cities. In our Final Report we will bring the focus to Melbourne specifically and, as far as can be determined with existing data, greenhouse emissions per

¹ Greenhouse emissions are usually measured as a carbon dioxide equivalent: CO₂e. That is to say, when other greenhouse gases such as methane are included the effect is related to the equivalent amount of warming produced by carbon dioxide.

passenger kilometre traveled per mode of transport. We will also discuss issues, trends and potential future changes, and implications for Melbourne City Council (MCC) policy.

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Symbols and Abbreviations

ABARE – Australian Bureau of Agricultural and Resource Economics
ABS – Australian Bureau of Statistics
ABS SMVU – Australian Bureau of Statistics Survey of Motor Vehicle Use
ACG – Apelbaum Consulting Group
AGO – Australian Greenhouse Office
BTRE – Bureau of Transport and Regional Economics
CBD – Central Business District
CH₄ – Methane
CO – Carbon Monoxide
CO₂ – Carbon Dioxide
CO₂ Equivalent – Carbon Dioxide Equivalent
EF – Fuel Consumption Emission Factors
FCR – Fuel Consumption Rates
GAMUT – Governance and Management of Urban Transport
GDP – Gross Domestic Product
Gg - Gigagrams
GHG – Greenhouse Gas(es)
GL - Gigalitres
GWP – Global Warming Potential
HFC - Hydro Fluorocarbons
IPCC – Intergovernmental Panel on Climate Change
kg – Kilograms
KMT – Kilometres Traveled
LPG – Liquefied Petroleum Gasoline
N₂O – Nitrous Oxide
NGGI – National Greenhouse Gas Inventory
NMVOC – Non-Methane Volatile Organic Compound
NO_x – Oxides of Nitrogen
PJ – Pet joule
PFC - Per Fluorocarbons
SF₆ – Sulphur Hexafluoride
SO₂ – Sulphur Dioxide
UNFCCC – United Nations Framework Convention on Climate Change
VHC – Volatile hydrocarbons
VKT – Vehicle Kilometres Traveled
VP – Volatile Particulates

Units

Units used in this report are grams (g), litres (l), and metres (m) with the standard SI prefixes.

kilo (k)	=	10 ³ ('thousand')
mega (M)	=	10 ⁶ (million)
giga (G)	=	10 ⁹ (billion)

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1.0 Introduction

Australia is a highly urbanized society. With approximately 64 per cent of the Australian population residing in its eight capital cities (Australian Bureau of Statistics, 2006b), the challenge is how to structure the city with minimal impact to the natural environment. One of the key challenges for urban sustainability is the transport sector because of the role it plays in the economy, the level of resources it consumes, the wastes produced, and the resulting array of direct and indirect social and environmental impacts. Of particular importance is the role of transport as a major source of greenhouse gas (GHG) emissions and its contribution to climate change. According to the 2004 National Greenhouse Gas Inventory (NGGI), the transport sector is responsible for 13.5 per cent of Australia's net GHG emissions, 89 per cent of which is from road transport (Australian Greenhouse Office, 2006c, p7-8).

Transporting people and goods within the city is a task facilitated by the complex infrastructure of roads, highways, railways and tramways. However, the environmental and social impact varies significantly among modes as each emits different levels of greenhouse gases. In an effort to reduce the amount of GHG emitted into the atmosphere by the transport sector, the national and state climate change policies have identified modal switching as one such effort (see Commonwealth of Australia, 1998). Further, the Intergovernmental Panel on Climate Change (IPCC) concluded in its 1996 Report on Technologies, Policies and Measures for Mitigating Climate Change that:

Changes in urban and transport infrastructure to reduce the need for motorized transport, and shift demands to less energy intensive transport modes, may be among the most important elements of a long-range strategy for greenhouse gas mitigation in the transport sector. In some circumstances, the resulting traffic reductions can result in greenhouse gas emission reductions of 10 per cent or more by 2020, while obtaining broad social and environmental benefits (IPCC, 1996 in Commonwealth of Australia, 1998p, 56)

In broad terms, strategies for mode switching to reduce GHG emissions concentrate on replacing private motor vehicle use with an array of public transport modes, notably trains, light rail (trams), and buses.

2.0 Methodology and Scope

A comparative approach was taken to identify organizations within Australia that generate data on GHG emissions per mode of transport for Australian capital cities. Once identified, data sets were compared to determine the most comprehensive one that reports GHG emissions per mode for each capital city. Factors considered when analyzing data sets included types of emissions emitted per transport mode (which GHG are assessed; is carbon dioxide (CO₂) the only gas recorded or is methane (CH₄) and nitrous oxide (N₂O) included?), source used for primary data (ABS or industry figures), methodology used to assess data (top-down versus bottom-up approach), and scope of the data set (National, State and/or City). This checklist identifies the preferred data set to be used to generate figures on transport mode GHG emissions per capita and per kilometre traveled for each capital city. The second part to this report identifies variables which impact GHG emissions assessed based on forecast and/or scenario availability, scale, transport modes reported, and the influence/impact each variable has on GHG emissions.

This report is divided into two parts. The task of the first part is to assess data sets that report emissions for land-based transport including road transport (i.e. passenger cars, buses, commercial vehicles and motorcycles), trams and trains (see Table 1). In the second part of the report we consider what factors affect greenhouse emissions from urban transport.

Aviation and shipping fall outside the parameters of this study. Land-based transport includes transportation of people, as well as freight. Therefore, emissions emitted by commercial/freight transport (i.e. light commercial vehicles, rigid trucks and articulated trucks) are also included. It

is important that freight be considered as it plays a significant role in the level of GHG generated. Light commercial vehicles often play a dual role of passenger and freight transport, for instance when they bring a tradesperson to the place of work.

In this report all of the Australian capital cities will be included for comparative purposes since the data is available in the data sets reviewed.

Table 1: Breakdown of Transport Modes

Infrastructure Type	Occupancy Type	Transport Mode
Road Transport	Passenger Vehicles	Passenger Cars Buses Motorcycles
	Freight Vehicles / Commercial Vehicles	Articulate Trucks Rigid Trucks Light Commercial Vehicles (LCV)
Rail Transport	Passenger Rail	Trains Trams
	Freight Rail	Trains

PART 1

A COMPARATIVE STUDY OF GREENHOUSE GAS DATA SETS

3.0 Analysis

3.1 Geographic Regions Assessed

All of the Australian capital cities (Sydney, Melbourne, Brisbane, Perth, Adelaide, Canberra, Hobart, and Darwin) are examined in this study. Each city region is defined geographically by its metropolitan/city boundaries, which consists of the central business district (CBD) as well as the inner and outer suburbs. These regions are considered collectively as 'statistical divisions' as defined by the national census (Kenworthy, 1999, p26).

According to the Australian Bureau of Statistics (ABS), a statistical division is an 'Australian Standard Geographical Classification defined area which represents a large, general purpose, regional type geographic area. Statistical divisions represent relatively homogeneous regions characterized by identifiable social and economic links between the inhabitants and between the economic units within the region, under the unifying influence of one or more major towns or cities. They consist of one or more statistical subdivision' (Australian Bureau of Statistics, 2006a). The ABS provides annual information on transport collected via their Survey of Motor Vehicle Use (SMVU).

3.2 Greenhouse Gases and Climate Change

Greenhouse gases are those constituents of the earth's atmosphere that absorb and emit radiation and create the 'greenhouse effect'. Water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone are the principle naturally-occurring GHGs, but there are also a number of synthetic gases, such as the halocarbons, that also contribute to the greenhouse effect (notably, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆)). Concentrations of naturally-occurring GHG have been increasing due to human activity (together with the lesser effects of several artificial GHGs). Fossil fuel combustion, land clearance, rice farming, cattle grazing, and industrial processes are the major sources of GHG arising from human activity.

Australia's *National Greenhouse Strategy* (Commonwealth of Australia, 1998) sets out the nation's response to the challenges of climate change by identifying goals, principles, and a series of policy responses in partnerships between government, industry, and the community, on energy efficiency and supply, transport and urban planning, sinks and land management, waste management, and adaptation. GHG emissions are monitored and recorded annually in the NGGI. Each of the Australian states and territories has their own climate change strategies, as do a number of local governments and corporations. A major focus of these strategies is the reduction of fossil fuel combustion from the energy, transport, industry, and agriculture sectors, which are the primary sources of CO₂, (the major GHG) (IPCC, 2001).

3.3 Fuel Used to Generate Traction

According to the BTRE (2002) report, Australian domestic transport currently consumes 'in the order of 30 gegalitres (GL) – i.e. 30 billion litres – of petroleum fuels per annum' (Bureau of Transport and Regional Economics, 2002a, p11). Consequently, the transport sector is the second largest primary energy consuming sector accounting for 24 per cent, and is the largest energy consuming sector at the end stage accounting for 39 per cent of final energy consumption (ABARE, 2005, p29-32). In 1998, the dominant transport fuel was automotive petroleum (18 GL), followed by automotive diesel oil (7.5 GL), liquefied petroleum gas (LPG) (2 GL), and fuel oil, natural gas, coal, ethanol and electricity at less than five per cent of the fuel source consumed (Bureau of Transport and Regional Economics, 2002a, p11). Transport modes vary in type of fuel consumed. Cars are primarily fueled by petrol for the exception of taxis which use LPG; the light commercial vehicle fleet consumes a mixture of petrol and

diesel; heavy trucks use diesel; and, railways consume a mixture of electricity and diesel (Bureau of Transport and Regional Economics, 2002a, p47).

3.4 Identification of Available Data sets

Four main data sets are available in Australia that report on GHG emissions by transport mode (see Table 2): the Apelbaum Consulting Group (ACG) (2006) data set, the Australian Greenhouse Office (AGO) (2006) data set, the Bureau of Transport and Regional Economics (BTRE) (2002 and 2003) data set, and the Kenworthy and Laube study (1999) data set. Other data sets produced within Australia, including the Allen Consulting Group report *Deep Cuts in Greenhouse Gas Emissions: Economic, Social and Environmental Impacts for Australia* (2006), and the CSIRO report *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions* (2005a), contain information on GHG emissions, however attention paid to the transport sector is limited and therefore difficult to derive the necessary information desired for this report. The following is an overview of four organizations identified as providing the most comprehensive information on transport-related GHG emissions.

Table 2: List of Available Data sets

Author(s)	Report Title and Year of Publication
Apelbaum Consulting Group	<i>Australian Transport Facts 2006</i> (2006)
Australian Greenhouse Office, Commonwealth Government of Australia	<i>National Greenhouse Gas Inventory 2004</i> (2006)
Bureau of Transport and Regional Economics, Commonwealth Government of Australia	<i>Greenhouse Gas Emissions from Transport: Australian Trends to 2020</i> (2002) <i>Urban Pollutant Emissions from Motor Vehicles: Australian Trends to 2020</i> (2003)
Kenworthy and Laube	<i>An International Sourcebook of Automobile Dependence in Cities 1960-1990</i> (1999)

Apelbaum Consulting Group

Apelbaum Consulting Group Pty Ltd. (ACG) is a private consulting company that undertakes detailed transport, management and environmental analysis for both the private sector and government. In comparison to the BTRE and AGO data sets, Apelbaum Consulting Group generates most of their data from accounting frameworks developed internally, rather than from ABS generated data. The document entitled *Australian Transport Facts 2006* contains information on GHG emissions per mode of transport broken down to the state/territory and urban levels. This publication appears to be referenced frequently in other GHG-related documents, appearing consistently alongside the ABS. A comparative analysis of methodology between the four data sets is possible using Apelbaum's methodology section.

Australian Greenhouse Office

The National Greenhouse Gas Inventory (NGGI) is produced annually by the AGO, an entity within the Federal Department of Environment and Heritage. Delivering the majority of programs under the Australian Government's \$AUS 1.8 billion climate change strategy, the AGO invests resources into greenhouse research and monitoring of Australia's progress towards its Kyoto Protocol GHG emissions target,² producing annually the NGGI (Australian Greenhouse Office, 2006a). The latest publication entitled *National Greenhouse Gas Inventory 2004* provides information on GHG emissions by each sector in Australia (including transport, land-use, industry, and energy).

² Australia GHG emissions target for the first commitment period of 2008—2012 under the Kyoto Protocol is 108% of its 1990 level.

Bureau of Transport and Regional Economics

The Bureau of Transport and Regional Economics is a division within the Federal Department of Transport and Regional Services. The Bureau's mandate is to improve the understanding of the economic factors influencing the transport sector and regional Australia by conducting and disseminating the results to government and community on relevant, high quality applied economic research and on a range of information products (Bureau of Transport and Regional Economics, 2006b). The BTRE 2002 report entitled, *Greenhouse Gas Emissions from Transport: Australian Trends to 2020*, and the 2003 follow-up report entitled *Urban Pollutant Emissions from Motor Vehicles: Australian Trends to 2020* contain data sets on carbon dioxide equivalent (end-use) emissions broken down by transportation mode (total GHG per mode) for each Australian capital city.

Kenworthy and Laube 1999 Study

The research team consisting of Dr. Jeff Kenworthy and Mr. Felix Laube is based at Murdoch University's Institute for Sustainability and Technology Policy located in Perth, Australia. Dr. Kenworthy is an associate professor at the Institute for Sustainability and Technology Policy with extensive experience in comparative urban research, consulting and policy covering the fields of traffic engineering, private and public transport, urban planning and design, housing and energy (Institute for Sustainability and Technology Policy, 2006). Mr. Felix Laube is currently working as a researcher at Murdoch University. Their 1999 study is entitled *An International Sourcebook of Automobile Dependence in Cities 1960-1990*.

3.5 Assessment of Available Methodologies

Several different methodologies are used by the four data sets to assess GHG emissions emitted per mode of transport. Before focusing the analysis on methodological approaches between the four identified data sets, a discussion on carbon dioxide equivalent, direct versus indirect emissions, and bottom-up versus top-down methodological approaches will explain the key characteristics of GHG monitoring for the transport sector.

3.5.1 Key Features of Emission Analysis

Carbon Dioxide Equivalent

To compare GHG emission levels, it is necessary to know the contributions of each gas to global warming. For example, automobiles produce three direct GHG including CO₂, CH₄, and N₂O. On average, CO₂ emissions account for approximately 94 to 95 per cent of GHG emitted by automobiles, while CH₄ and N₂O represent only five to six per cent (United States Environmental Protection Agency, 2005, p4). For a given mass of each GHG, its contribution to global warming is calculated as a 'global warming potential' (GWP), which compares it to an equivalent mass of CO₂ over a specified period. These values are used to convert the six main GHGs under the UNFCCC to a single measure, known as the 'carbon dioxide equivalent' (using the notation CO₂e). By calculating CO₂e values the GHG emissions from different fuel sources for each transport mode can be compared.

Direct versus Indirect Emissions

Two main sources of GHG emissions are generally reported for transport: direct and indirect emissions. *Direct emissions* are those emissions arising in the same time and place as the emitting activity; in the case of motor vehicles, the emissions arise primarily from the vehicles' combustion of fossil fuels. These direct emissions are often referred to as 'end-use' emissions (Australian Greenhouse Office, 2005, p1). *Indirect emissions* are those that occur in a different time and/or place from the causal activity. In the case of fossil fuels consumed in motor vehicles, there are a host of emissions resulting from the extraction, processing, manufacture, transport, and handling of fossil fuels before those fuels are used in motor vehicles. Urban rail and light rail use electric power provided by overhead lines, electric rails, and other means from electricity generated remotely. Accounting for the GHG emissions attributable to public

transport has to take account of emissions created by electricity generation through coal, natural gas, oil, and other fuel types which vary among states³. Inventories that record only the direct emissions, sometimes under-report total emission. However, the calculation of indirect emissions is a complex and usually difficult exercise.

Indirect emissions associated with transport include carbon monoxide (CO), oxides of nitrogen (NOx) and non-methane volatile organic compounds (NMVOCs) (Bureau of Transport and Regional Economics, 2002a, p2). The indirect gases are not radiative and therefore do not have global warming potential. In accordance with the IPCC reporting guidelines, gases that do not have such potential are reported generally as individual units but are not included as CO₂e (Australian Greenhouse Office, 2006d, p9). Three of the four data sets report direct emissions as specified by the IPCC.

Bottom-Up Versus Top-Down

Bottom-up and top-down modeling are available as techniques to measure GHG emissions. In general, *top-down* approaches begin with the highest level of abstraction and, using general principles, derive more detailed information, whereas *bottom-up* approaches begin with individual components and aggregate these into higher scales. Calculating CO₂ emissions can be achieved through a macro-modeling approach where emissions for the transport sector are modeled as part of the total economy (Bureau of Transport and Regional Economics, 2003a, p1) where the understanding of how the fuel was used or what intermediate transformations it underwent is not important (i.e. 'top-down') (Intergovernmental Panel on Climate Change, 1997, p9). Comparatively, the bottom-up modeling approach sums the GHG emissions across the major transport sectors (typically calculated using vehicle fleet models or activity-specific econometric equations) (Bureau of Transport and Regional Economics, 2002a, p2). As the premise of this report is to identify GHG emissions per mode of transport for each capital city, bottom-up approaches are likely to be more accurate because they use data collected closer to the scale of our inquiry.

3.5.2 Methodology Used

The following section offers a comparison of the methodological approaches undertaken by the four identified data sets (A summary of the analysis is presented in Table 3).

³ Fuel used by the rail network throughout Australia varies between states. New South Wales, Queensland, South Australia and Western Australia use black coal as the major fuel to generate electricity; natural gas is also present but in much smaller quantities. Victoria comparatively uses brown coal with natural gas (Bureau of Transport and Regional Economics, 2002a).

Table 3: Summary of Data Sets

Factors		Data sets			
		ACG	AGO	BTRE	Kenworthy and Laube
Emission Source	Direct	X	X	X	X
	Indirect	X			X
CO ₂ Equivalent	CO ₂	X	X	X	X
	CH ₄	X	X	X	
	N ₂ O	X	X	X	
Approach to Data Collection	Top-Down		X		
	Bottom-Up	X		X	X
Transport Modes Considered	Passenger Car	X		X	X
	Bus	X		X	X
	Freight Vehicle	X			
	Passenger Rail	X		X	X
	Freight Rail	X			
	LCV	X			
	Motorcycle	X		X	X
	Total Numbers		X		
Scale	National			X	
	State/Territory	X		X	
	City	X	X	X	X
Primary Data Source	ABS		X	X	X
	ABARE		X		
	ACG	X		X	
	BTRE			X	
	AGO				
	Industry		X		
Follows IPCC Guidelines	Yes	X	X	X	
	No				X

Apelbaum Consulting Group

Unlike the BTRE and the AGO which both derive primary data from the ABS SMVU, Apelbaum (ACG) collects and generates its own data via a framework developed internally. According to ACG, the data obtained is derived from relevant transport associations, surveying of private industry, State, Territory and federal Government agencies, and public domain data (Apelbaum Consulting Group, 2006, p43). Apelbaum Consulting Group does not draw data from the ABS as they suspect that field numbers gathered for the transport sector are misleading. Apelbaum argues that the motor vehicle census used by the ABS to derive their numbers is not a census of Australian road vehicles (Apelbaum Consulting Group, 2006, p39). According to ACG, a motor vehicle census should reflect a periodic counting of the total (registered and non-registered) Australian vehicle population and the gathering of associated statistics. However, the census published by the ABS, is a compilation of motor vehicle 'registration' statistics as prepared by various state and territory registration authorities, thus only a proportion of the total vehicle population⁴ (Apelbaum Consulting Group, 2006, p39). According to ACG, any correlation between total fuel consumed, distance traveled and fuel consumption rates needs to reflect all vehicles consuming fuels, including non-registered vehicles (Apelbaum Consulting Group, 2006, p46).

In response to this criticism, the ABS has stated on its website that the Bureau is making plans to 'undertake a separate analysis to identify the characteristics of unregistered vehicle use (using data from police records, State and Territory authorities, mining and agricultural industry groups)'; this will assist in determining the extent to which non-registered vehicles impact (i.e. change) the total vehicle kilometres traveled (VKT) of the current sample frame⁵ and whether this impact will significantly alter the level of GHG emitted (Australian Bureau of Statistics, 2005a). This analysis may lead to further understanding the proportion of non-registered to registered vehicles on the road, and whether the proportion is great enough to influence considerably the level of GHG emitted.

The ACG assessment of GHG emitted per mode of transport adopts the 1997 IPCC Guidelines understanding of direct and indirect emissions. Emissions from transport are derived from the full fuel cycle emission factors, distance traveled by transport vehicles and the direct energy consumed (Apelbaum Consulting Group, 2006, p43). In all instances, emissions for each of the direct and indirect gases are separately identified by ACG to allow variation to the CO₂ equivalent estimates (Apelbaum Consulting Group, 2006, p43). This methodology of singling out the various emission types is the same approach taken by the BTRE in their 2003 follow-up report *Urban Pollutant Emissions from Motor Vehicles: Australian Trends to 2020* (Bureau of Transport and Regional Economics, 2003b). The advantage of this approach is that the data is deconstructed to a level where an understanding of concentration levels of the various GHG available can be obtained. Furthermore, much like the BTRE approach, the ACG analysis reflects a comprehensive 'bottom-up' analytical framework involving urban, provincial urban and non-urban regions in each state/territory (Apelbaum Consulting Group, 2006, p38).

The methodology used to capture the level of GHG emitted per mode of transport in cities is similar to that used by the BTRE. Fuel and energy consumed by road vehicles is apportioned to states/territories according to the state/territory registration of vehicles, where rail accounting frameworks developed for energy consumed by rail operators include total fuel/energy consumed by operators whose head office is domiciled within the nominated state/territory (Apelbaum Consulting Group, 2006, p42). Emissions from transport are then derived from full fuel cycle emission factors, distance traveled by transport vehicles and the direct energy consumed including a consideration for the component of fuel that is not yet oxidized (Apelbaum Consulting Group, 2006, p43). Emissions from electricity are calculated differently as the emissions produced arise at the source and not at the end-use. This framework is

⁴ According to ACG, "the disparity between the total vehicle park and registrations is likely to be significant for all vehicle categories with the exception of passenger vehicles. This is particularly evident for freight vehicles and motorcycles where new vehicle sales have consistently exceeded new vehicle registrations. For example, in 2002, new truck registrations constituted 88.3 per cent of new truck sales" (Apelbaum Consulting Group, 2006).

⁵ The ABS uses the Motor Vehicle Census as their sample frame (Apelbaum Consulting Group, 2006).

particularly relevant for electrical powered transport operating in urban areas where end-use consumption is in the metropolitan environs, but emissions are generated at power facilities located outside the metropolitan urban regions (Apelbaum Consulting Group, 2006, p43).

Australian Greenhouse Office

Each year, the AGO produces a series of inventories reporting on GHG emissions per sector in Australia. Data available in the reports are compiled in accordance with the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Intergovernmental Panel on Climate Change, 2000), and the *Revised 1996 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories* (Intergovernmental Panel on Climate Change, 1997). The UFCCC requires that Annex I countries report annually on their GHG emissions following a general reporting structure established by the IPCC.⁶ Thus the data sets provided in the Australian inventory and its subsequent publications (see Table 4) provide only a broad overview of GHG emitted per sector as required by the IPCC, thus exemplifying a top-down approach.

Table 4: Series of GHG Publications by the Australian Greenhouse Office

Publication	Description
National Greenhouse Gas Inventory 2004 (Australian Greenhouse Office, 2006c)	A compilation of data at the national level, however the breakdown is between sectors (agriculture, energy, transport, etc) without a further breakdown of modes within each sector.
Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sink – Energy (Transport) (Australian Greenhouse Office, 2006b)	A workbook for calculating GHG emissions in the transport sector
State and Territory Greenhouse Gas Emissions – An Overview (Australian Greenhouse Office, 2006f)	A breakdown by States/Territories of GHG emissions emitted per sector. However the document stops short of breaking down the emissions by mode of transport.
Victoria Greenhouse Gas Inventory (Australian Greenhouse Office, 2006g)	A breakdown by State/Territory by the type of GHG emitted per sector, however does not go as far as breaking down the emissions by mode of transport.

The GHG covered by the inventory include CO₂, CH₄, N₂O, PFCs, HFCs, and SF₆, as well as indirect gases including CO, NOx and NMVOCs (Australian Greenhouse Office, 2006c, p2). The reporting structure is similar to that of the ACG where each GHG type is reported individually, allowing for the relative impact of each gas to be compared. The emissions of the direct gases are aggregated by converting them to CO₂e by multiplying the mass of emissions by the appropriate GWP factors (Australian Greenhouse Office, 2006c, p2). It is important to reiterate that the indirect effects of gases including CO, NOx and NMVOCs do not have greenhouse potential and therefore, in accordance with the IPCC guidelines are not included in the inventory total (Australian Greenhouse Office, 2006d, p9).

The NGGI relies on the published data produced by leading statistical institutions including the Australian Bureau of Agricultural and Resource Economics⁷ (ABARE) who provide figures on

⁶ Under the FCCC, developed nations are listed in Annex I of the framework convention; these were essentially the OECD nations at the time the framework convention was created.

⁷ The Australian Bureau of Agricultural and Resource Economics is an Australian government economic research agency who's main objective is to 'contribute to the competitiveness of

primary and end-use energy consumption by industry and by state within Australia (see Appendix A for example charts listing energy consumption and Appendix B for petrol sales), and the ABS, as well as data collected from industry consultants who maintain strict quality control processes (Australian Greenhouse Office, 2006d, p9). Primarily the data reported on is produced by the ABS, an organization that maintains an active review process of its sample frame, survey design, coverage and editing processes required to produce its data series (Australian Greenhouse Office, 2006d, p10). Furthermore, the ABS consults actively with stakeholders in the review of its data collection activity (Australian Greenhouse Office, 2006d, p10).

Bureau of Transport and Regional Economics

The BTRE emission estimates are partly based on data supplemented by the ACG, nonetheless, the BTRE 2002 report and the 2003 follow-up report draws much of its primary information from the annual ABS SMVU (Bureau of Transport and Regional Economics, 2002a, p6). Although the ABS provides extensive information on the transport sector, the methodology used to gather data lacks consistency across its time series which is problematic for the BTRE who use baseline data from the ABS survey results to forecast future emission scenarios.

The BTRE offers a critique of the ABS suggesting that the changes that have occurred annually to the survey's scope including vehicle classification and collection methods have created problems of inconsistency. Hence the ABS 'should be standardized across the survey years, before trend growth rates can be derived from them' (Bureau of Transport and Regional Economics, 2002a, p5).

International reporting standards as identified by the IPCC encourage all countries to report on their GHG emissions by sector (Intergovernmental Panel on Climate Change, 1997). Additionally, all emission values are to be given as CO₂ equivalents incorporating only direct emissions (i.e. they include solely the effects of the direct radiative gases emitted from transport which consist of CO₂, CH₄ and N₂O) (Bureau of Transport and Regional Economics, 2002a, p2). Using a bottom-up approach, the BTRE apportions data from the state/territory emission figures to urban/non-urban figures to reflect transport patterns in each capital city in Australia. Transport emissions are based on the BTRE estimates of the urban transport task which includes passenger cars, commercial/freight vehicles, motorcycles, buses and urban passenger rail/tram (Bureau of Transport and Regional Economics, 2002a, p66).

The methodology used to capture GHG emitted per mode of transport per city focuses on apportioning metropolitan information from state/territory data utilizing a number of approaches. Capital city emissions for passenger cars are calculated from state/territory emission estimates apportioned using the percentage of the state/territory population residing in the capital, and a scale factor reflecting the different rate of fuel use between urban and non-urban areas for that state/territory (Bureau of Transport and Regional Economics, 2002a, p66). It is important to note that fuel use per person varies due to different vehicle utilization patterns in urban and non-urban areas (Bureau of Transport and Regional Economics, 2002a, p66). For example, metropolitan areas generally have more congestion contributing to a greater level of emissions produced than would otherwise be the case in a rural traffic setting with less congestion.

Bus emissions are apportioned between capital city and non-metropolitan values using data on location of vehicle operation from the ABS SMVU (Bureau of Transport and Regional Economics, 2002a, p66). For urban rail passengers, the BTRE includes emissions from urban passenger rail transport, whereas rail freight movements within capital cities, which are likely to be a smaller proportion of the total rail freight task, are not included (Bureau of Transport and Regional Economics, 2002a, p66). In estimating urban commercial/freight transport fuel use

Australia's agricultural, fishing, forestry, energy and minerals industries and the quality of the Australian environment by providing rigorous and independent economic research analysis and forecasting" (Australian Bureau of Agricultural and Resource Economics, 2006).

and emissions, the BTRE investigated the difference in fuel efficiency of urban operations relative to non-urban travel (Bureau of Transport and Regional Economics, 2002a, p66). The BTRE estimates an econometric model of aggregate urban freight movements for each capital city to 2020, where changes in capital city population are based on ABS projections of population from 1996 to 2020, as supplied to the BTRE by the AGO (Bureau of Transport and Regional Economics, 2002a, p66). The econometric model relates the road freight task in capital cities and provincial urban areas to national per capita gross product, population and real road freight rates (Bureau of Transport and Regional Economics, 2002a, p66).

Kenworthy and Laube (1999) Study

Dr. Jeff Kenworthy articulated a need to compare international cities against one another on factors which include transport, land-use and environment (Planning and Transport Research Centre, 2006). As a result, a collaboration evolved with Felix Laube and others (Peter Newman among them) to compile comparative data on 46 major global metropolitan cities on transport related matters over a time period of 30 years. The publication entitled *An International Sourcebook of Automobile Dependence in Cities 1960-1990* includes Sydney, Melbourne, Brisbane, Adelaide and Perth in its analysis.

The international focus of this study acts as a key limitation, as inconsistencies evolve regarding data collection methodologies between international cities. Techniques and methods used to collect and analyze data are not standardized across countries. Additionally, data collection timeframes between countries are also inconsistent. For example, Australia's census is every five years, whereas the United States census is every ten (Kenworthy, 1999, p3). The researchers therefore have the daunting task of sorting through data and using only data that can be compared against countries that report the same year. These inconsistencies between countries limit the type of data and how often the data is reported for Australian cities. The data attained for the Australian cities are obtained from the ABS SMVU (Australian Bureau of Statistics, 1993).

Emissions of CO₂ are calculated for each public and private mode of transportation using standard rates of CO₂ emissions per capita in kilograms (Kenworthy, 1999, p603). A bottom-up approach is taken to address the patterns of emissions across each mode of transport within the city. Each mode of transport is described in terms of 'private transportation', 'diesel transportation' and 'electric public transportation' (Kenworthy, 1999, p602); therefore details for bus, motorcycle, car, and passenger rail specifically are not provided. For electric transportation, the rate of CO₂ emissions is adjusted to reflect detailed national data on how electricity is generated, what type of fuel is used to generate electricity and transmission losses from power stations (Kenworthy, 1999, p24).

Carbon dioxide equivalent and its associated direct gases are not reported, as CO₂ alone is considered to be the 'ultimate end product of fossil fuel combustion' (Kenworthy, 1999, p602). There are however, a number of additional emissions including NO_x, sulphur dioxide (SO₂), carbon monoxide, volatile hydrocarbons (VHC), and volatile particulates (VP) that are reported for each city, but are not broken down per mode of transport within the study.

3.6 Identification of Preferred Data Set

Four data sets were considered. For the purpose of this study, purchasing the ACG document *Australian Transport Facts 2006*, could not be justified assuming that the BTRE and AGO data sets, which both heavily reference ACG data, are adequate. Therefore little need existed to purchase the ACG document as the information might be redundant. The data available by the AGO was not sufficient to meet the demands of this research study. GHG emissions produced by the AGO are deconstructed by sector, however, they are not broken down to sub-sectors. Additionally, the AGO do not break down data by state/territory and city. Lastly, the information provided by Kenworthy and Laube (1999), although relatively comprehensive, contain shortfalls including failing to record GHG emissions as CO₂ equivalents, failing to document CH₄, and only breaking down CO₂ as a single component of GHG emissions.

Data found in the 2002 and 2003 BTRE publications provide the most sufficient overview of GHG emissions per mode of transport for each capital city in Australia. As the BTRE contains the most comprehensive data, it is therefore selected as the preferred data set.

3.7 Major Assumptions and Limitations to the Preferred Data Set

The sample frame for the BTRE data is the ABS SMVU. According to some critics (i.e. ACG) this is a key limitation to the comprehensiveness of the BTRE data set. As noted earlier, the collection methods of the ABS incorporate only those vehicles that are registered (Australian Bureau of Statistics, 2006c) and not those vehicles that are not registered, hence there are emissions from a fleet of automobiles not considered. Referenced throughout the BTRE report is ACG. This reference is found in the tables which look at capital city CO₂ equivalent emissions (end-use) for passenger cars, buses, and passenger rail. Perhaps the assumption can be made that by incorporating data derived by ACG any perceived inadequacies of the BTRE data set are minimized.

4.0 Additional Data Sets

There is an additional database available for a charge of approximately \$AUS 1,000 entitled the *Millennium Cities Database for Sustainable Transport* (Institute for Sustainability and Technology Policy, et al, 2001) produced by the Institute for Sustainability and Technology Policy (ITP) in collaboration with Dr. Jeff Kenworthy and Mr. Felix Laube of Murdoch University in Australia. A comprehensive study of 100 global cities, this database assesses each city on the merits of 200 indicators for the baseline year 1995. Sydney, Melbourne, Brisbane and Perth are among the cities analyzed. The database measures population, economy and urban structure, number of road vehicles, public transport networks, choice of transport mode, transport system efficiency and environmental impact. Particular indicators of interest include:

- Total emissions per capita
- Emissions of CO per capita
- Emissions of SO₂ per capita
- Emissions of VHC per capita
- Emissions of NO_x per capita
- Total emissions per urban hectare
- Total emissions per total hectare
- Public transport energy use per capita
- Total transport energy use per capita
- Energy use per private passenger vehicle kilometre
- Energy use per public transport vehicle kilometre
- Energy use per bus vehicle kilometre
- Energy use per minibus vehicle kilometre
- Energy use per tram wagon kilometre
- Energy use per light rail wagon kilometre
- Energy use per metro wagon kilometre
- Energy use per suburban rail wagon kilometre
- Energy use per heavy rail wagon kilometre
- Energy use per private passenger kilometre
- Energy use per public transport passenger kilometre
- Energy use per bus passenger kilometre
- Energy use per minibus passenger kilometre
- Energy use per tram passenger kilometre
- Energy use per light rail passenger kilometre
- Energy use per metro passenger kilometre
- Energy use per suburban rail passenger kilometre
- Energy use per heavy rail passenger kilometre
- Overall energy use per passenger kilometre

(Institute for Sustainability and Technology Policy, et al, 2001)

This data set does not report on the three direct GHGs (CO₂, CH₄, and N₂O) as specified by the IPCC Guidelines. However the figures for energy use per mode can be converted to emissions per mode using figures derived elsewhere for emissions from different energy sources. The advantage of this data set is the comprehensiveness of the transport related variables reported as well as the transport modes examined (i.e. passenger car, public transport, bus, minibus, tram, light rail, metro wagon, suburban rail wagon and heavy rail wagon).

5.0 Identification of GHG Transport Emissions for Each City

As noted above, road transport, particularly the passenger car⁸ with 89 per cent of emissions, is the largest emitter of GHG in the transport sector (Australian Greenhouse Office, 2006c, pp7-8). Thus, the purpose of this section is to deconstruct the BTRE 2002 and 2003 data set on GHG emissions per mode of transport for each capital city to per capita and per kilometre traveled figures; this will help in understanding how much GHG emissions are generated per mode of transport within each capital city. The tables presented in this section illustrate GHG emission levels for each mode of transport over a time period from 1990 to 2000, then forecast from 2001 to 2020.

5.1 Total GHG Per Mode of Transport

Emission figures for each mode of transport are reported in gigagrams (Gg) of CO₂e for passenger cars, commercial/freight vehicles, buses, motorcycles, and passenger rail for each capital city in Australia. Data is available for the years 1990 through to 2000 and forecast results are available for 2001 onwards to 2020. The data of particular interest for this section is that available from 1990 to 2000 as it provides actual year-specific data on GHG emissions. This data provides the base data from which per capita and per kilometres traveled figures are generated in the following sections.

It is interesting to note that total GHG emissions per mode of transport will vary between inner city and outer city based upon percentage of public transport use between the two zones. The distinction occurs as a result of the difference in the concentration of public transport between the zones. To illustrate the point, the following table (Table 5) provides a breakdown of public transport trips between inner (Zone 1) and outer (Zone 2) Melbourne for the years 2005 and 2006.

Table 5: Melbourne, Zone Breakdown of Public Transport Use

Zone	2005	2006
Within 1 (Inner)	49.3	49.6
Between 2 and 1	33.5	33.8
Within 3 (Outer)	17.2	16.6

(Source: MetLink)

These figures show that there is much greater usage of public transport, meaning higher public transport vehicle occupancy, within the inner zone which includes the City. This higher vehicle occupancy would make public transport a more 'greenhouse efficient' mode than is revealed by average figures for the city as a whole.

5.2 Total GHG Per Capita Per Mode

Total GHG emitted per mode of transport per capita for each city was calculated by dividing the total GHG emitted per mode of transport by the population in each city for each year (GHG

⁸ According to statistics by the ABS, in 2005, there were 13.9 million registered cars in Australia (Australian Bureau of Statistics, 2005b) compared to 769,000 in 1950 representing an almost nine fold increase over 50 years in total passenger travel in urban areas (Australian Bureau of Statistics, 2005c).

emissions per mode of transport and population figures were provided by the BTRE 2002 data set). The number derived in gigagrams was multiplied by 1,000,000 to convert to kilograms (kg). The results are summarized in Tables 5 and 6. The data sets can be found in Appendix C.

To make comparisons among cities it is necessary to calculate the per capita figure per mode of transport. When this is done, the relative impact between modes per person becomes apparent. Between 1990 and 2000 the total emissions per capita increased by 8.2 per cent in all of Australia, with the largest increase experienced by the passenger car at 10.37 per cent (see Table 7). Interestingly, emissions for buses went down from 521.09 kg per capita in 1990 to 492.68 kg in 2000, perhaps as the result of greater dependency on the private passenger car.

The data suggest a number of differences between the capital cities. For example, low density Canberra in 1990 was the largest emitter of CO₂e at 2,256 kg (see Table 5), this changed in 2000 when Melbourne took top position with 2,297 kg of CO₂e per capita; while Darwin had the lowest with 1,674kg CO₂e per capita (see Table 6). For commercial vehicles in 2000, the order is reversed, with Darwin having the highest emissions at 1,138.39 kg per capita CO₂e and Melbourne with 644.43 kg CO₂e per capita (see Table 6). Interestingly, the difference between the highest and lowest cities in 2000, Melbourne and Brisbane respectively, is about 16%, while the differences on a modal basis between the cities are often much greater (see Table 6).

In terms of ecological sustainability, these figures assist in articulating the importance of behavior change to reduce individual impact; or at least justify a greater emphasis towards policies that favor more sustainable forms of transport.

Table 6: GHG Emissions Reported as CO₂e Per Transport Mode Per Capita for each Capital City for the Year 1990 (kg)

	Sydney	Melbourne	Brisbane	Adelaide	Perth	Hobart	Darwin	Canberra
Population	3,632,100	3,127,200	1,330,600	1,046,900	1,173,700	188,800	75,200	282,800
Passenger Car	1,818.23	2,028.65	1,751.09	1,709.81	1,833.52	1,647.25	1,449.47	2,256.01
Commercial Vehicle	664.35	633.79	743.27	565.48	736.99	688.56	1,223.40	509.19
Passenger Rail	143.72	84.80	68.32	23.98	18.40	0.00	0.00	0.00
Bus	58.09	50.52	54.11	55.40	57.94	84.75	93.09	67.19
Motorcycle	9.86	9.15	16.53	5.25	6.22	12.18	18.62	7.43
Total Emissions	2,694.25	2,806.91	2,633.32	2,359.92	2,653.07	2,432.74	2,784.58	2,839.82

Table 7: GHG Emissions Reported as CO₂e Per Transport Mode Per Capita for each Capital City for the Year 2000 (kg)

	Sydney	Melbourne	Brisbane	Adelaide	Perth	Hobart	Darwin	Canberra
Population	4,094,100	3,463,500	1,624,700	1,097,600	1,385,200	19,300	89,600	31,200
Passenger Car	2,001.42	2,297.10	1,754.17	2,059.04	2,061.17	1,914.12	1,674.11	2,410.26
Commercial Vehicle	673.41	644.43	744.14	576.71	744.30	703.57	1,138.39	778.85
Passenger Rail	140.96	95.80	53.43	22.05	44.04	0.00	0.00	0.00
Bus	53.25	47.35	45.55	54.66	50.53	87.95	89.29	64.10
Motorcycle	8.84	8.34	13.73	5.01	5.34	11.90	16.74	6.73
Total Emissions	2,877.88	3,093.02	2,611.02	2,717.47	2,905.38	2,717.54	2,918.53	3,259.94

Table 8: Total GHG Emissions Reported as CO₂e Per Transport Mode Per Capita for 1990 and 2000 (kg)

	1990	2000
Population	10,857,300	11,805,200
Passenger Car	14,494.03	16,171.39
Commercial Vehicle	5,765.03	6,003.80
Passenger Rail	339.22	356.28
Bus	521.09	492.68
Motorcycle	85.24	76.63
Total	21,204.61	23,100.78

Table 9: Total GHG Emissions Reported as CO₂e Per VKT for Car and Bus in 1990 (kg)

City	Car			Bus		
	VKT Per Person	Petrol Emissions (kg)	Diesel Emissions (kg)	VKT Per Person	Petrol Emissions (kg)	Diesel Emissions (kg)
Sydney	6,467.33	1,730.01	2,427.19	52.04	18.21	38.78
Melbourne	7,217.32	1,930.63	2,708.66	43.49	15.22	32.41
Brisbane	6,793.93	1,817.38	2,549.76	63.88	22.36	47.60
Perth	6,807.53	1,821.01	2,554.87	59.64	20.87	44.44
Adelaide	6,208.81	1,660.86	2,330.17	59.22	20.73	44.13
Canberra	8,189.53	2,190.70	3,073.53	70.72	24.75	52.70
Hobart	5,985.17	1,601.03	2,246.23	90.04	31.51	67.10
Darwin	5,252.66	1,405.09	1,971.32	172.87	60.51	128.82

5.3 Total GHG Per Passenger Kilometre Traveled Per Mode Per Year

As noted at the beginning of this report, if we are to assess the validity, from the perspective of climate change mitigation, of encouraging a shift in travel modes, it is necessary to know the GHG emissions per passenger kilometre traveled within cities. This information assists policy-makers in their assessment of 'how effort might best be directed toward the achievement of reduction targets' (EPA, 1994, p20). However, extending the available data on emissions per mode to emissions per kilometre traveled for each city is hampered by lack of available data. Emissions data is only available for kilometres traveled per mode per city, without conversion to *emissions per passenger kilometre traveled* for each transport mode. However some data can be obtained and this is reported for Melbourne.

To calculate emissions per passenger kilometre, two factors must be considered: fuel efficiency (fuel consumed per unit distance traveled), and GHG emissions intensity (emissions per unit of fuel consumed). Often the relationship between these factors is expressed as follows:

$$\begin{array}{l} \text{Emissions} \\ \text{per} \\ \text{passenger-km} \end{array} = \begin{array}{l} \text{Energy used} \\ \text{per} \\ \text{passenger-km} \end{array} \times \begin{array}{l} \text{Emissions} \\ \text{per unit of energy} \\ \text{per mode} \end{array}$$

Three documents were identified as containing the information required to tabulate GHG emissions per passenger kilometre: Apelbaum Consulting Group's 2005 *Australian Transport Facts*; Kenworthy and Laube's 2001 *Millennium Database for Sustainable Transport*, and, the Australian Greenhouse Office's 2003 *Australia's National Greenhouse Gas Inventory 1990, 1995 and 1999*. Each of these documents provided for each mode of transport data on energy used per passenger kilometre and emissions per unit of energy. The problem, however, is that the data reported is quite dated. The earliest figures from the ACG was 1995, Kenworthy and Laube was 1996 and AGO was 1999.

The ACG publication did not report at the city level, but provided emissions per unit of energy for brown coal in Victoria. This assisted in tabulating data on heavy and light rail in Melbourne. The Kenworthy and Laube publication provided the most relevant data, reporting on transport specific to Melbourne. The AGO publication reported the most general information, providing data only at the national level. Table 10 summarizes the figures on emissions per passenger kilometre from each publication.

Although figures for emissions per passenger kilometre were difficult to obtain, the BTRE 2005 report provided figures for passenger kilometres traveled per kilogram of GHG emissions for the year 2004. This figure can be converted into the same terms as above: GHG emissions per passenger kilometre travelled (Table 11). The modes reported included electric passenger rail (both heavy and light rail), diesel heavy passenger rail and passenger vehicles. It is important to note however, that the figure reported for passenger kilometres for cars was derived assuming a 1.4 average occupancy rate (TravelSmart Perth, 2005). We believe that this figure for car occupancy is too high. We would expect the figure to be closer to 1.2 which would give a figure of about 212 rather than 181.16.

Table 10: Total GHG Emissions (grams CO₂e) Per Passenger Kilometre Traveled per Mode

Emissions (grams CO ₂ -e) Per Passenger Kilometre Travelled				
Transport Mode	BTRE (2004)	ACG (1994-5)	Kenworthy and Laube (1996)	AGO (1999)
Car (petrol)	181.16	248.47	212.74	210
Bus (diesel)		106.35	122.77	114
Train (brown coal)	116.95	184.53	N/A	162
Tram (brown coal)		288.63	37.11	178

Table 11: Total GHG Emissions (grams CO₂e) Per Passenger Kilometre Traveled per Mode (BTRE, 2004)

Emissions (grams CO ₂ -e) Per Passenger Kilometre Traveled	
Transport Mode	BTRE (2004)
Car (petrol)	181.16
Electric Passenger Rail (heavy and light rail)	116.95
Diesel Heavy Passenger Rail	75.47

Source: (Bureau of Transport and Regional Economics, 2005)

These figures show that there is considerable variation in assessments of transport greenhouse emissions by different agencies. The most recent assessment by the Bureau of Transport and Regional Economics indicates that, for the whole Melbourne metropolitan area, car use contributes significantly more greenhouse emissions to the atmosphere per passenger

kilometre traveled than the rail-based modes. Travel by high efficiency diesel buses produces significantly less emissions than travel by car. If the differential between inner and outer regions' vehicle occupancy is taken into account, the difference between cars and public transport modes would become much greater. Also the figures are dependent on accurate data for vehicle occupancy. There is reason to doubt that the figures collected do in fact accurately reflect vehicle occupancy. It seems probable that the figures for public transport modes somewhat underestimate vehicle occupancy.

The figures above provide a range of base-line 'business as usual' data. Of course the future could see the following major changes in emission profiles:

1. The energy source for electricity could see a reduction in CO₂e per unit through an increased proportion of renewable energy. If that were to occur, emissions from rail-based public transport would be greatly reduced.
2. The mix of vehicles in the Melbourne car fleet could change towards smaller, more energy efficient and greenhouse efficient cars. This would reduce the total emissions from car traffic.
3. Vehicle occupancy could increase. This is more likely for public transport than for private transport (car) modes. Higher vehicle occupancy would reduce emissions per passenger kilometre traveled.

PART 2

IDENTIFICATION OF GREENHOUSE GAS EMISSION VARIABLES

6.0 Identification of Variables Influencing GHG Emissions

The range of social, economic, technological, structural and policy variables that influence GHG emissions per mode of transport are vast. A summary of these variables can be found in Table 9. This section of the report examines those variables which appear frequently in the literature and are identified as major influences on GHG emissions. Each variable discussed has been recognized as a major factor in altering the level of GHG in the atmosphere directly, while others are assessed based on their influence upon VKT.

Table 12: Variable Definitions

<i>Social Variables:</i> variables which affect how people live and carry on their daily lives.
<i>Economic Variables:</i> matters which relate to how much money people have and what they can afford, as well as price of commodities.
<i>Technological Variables:</i> technological innovations including fuel efficiency.
<i>Structural Variables:</i> the urban design of a city which influences density and layout.
<i>Policy Variables:</i> government based decisions enforced through regulations to reduce GHG emissions.

From the perspective of vehicle emissions, it is generally held that three factors directly influence GHG outputs: VKT, fuel efficiency (fuel consumed per unit distance traveled), and GHG emissions intensity (emissions per unit of fuel consumed). Often the relationship between these factors is expressed as follows:

$$\begin{array}{c} \textit{Emissions} \\ \textit{per} \\ \textit{passenger-km} \end{array} = \begin{array}{c} \textit{Energy used} \\ \textit{per} \\ \textit{passenger-km} \end{array} \times \begin{array}{c} \textit{Emissions} \\ \textit{per energy use} \\ \textit{per mode} \end{array}$$

From a broader perspective, issues such as choice of mode, emission levels and rates from each mode, and energy use are influenced by social, economic, technological, urban structure, and policy variables. Variables which influence emissions include the means by which people travel (i.e. mode choices), how far they travel (i.e. VKT), fuel type (i.e. ‘emissions intensity’), vehicle efficiency, vehicle occupancy, population, GDP, urban structure, and demand management. It is important to note that each variable can act independently on VKT and GHG emissions as well as collectively with other variables (i.e. population forecasts and rising GDP can act together to influence GHG emissions emitted per mode). In addition to identifying variables, this section will also outline the data available on these variables, and identify existing forecasts and scenarios. A summary of the variables can be found at the end of this section in Table 11.

6.1 Fuel Type

The type of fuel consumed, whether it is diesel, petroleum, LPG, or compressed natural gas, will affect the quantity of GHG emitted. This difference may be attributed to the amount of carbon and energy potential each fuel contains, which has implications for fuel economy and GHG emissions emitted per mode per kilometre traveled (Australian Greenhouse Office, 2006e). Table 10 lists the amount of CO₂ emitted from the common fuel types. Since the carbon content of the fuel is the major determinant of its CO₂ emissions, reducing emissions from vehicle fleets using strategies involving fuel-type are primarily achieved by ‘fuel switching’.

Table 13: CO₂ Emitted Per Litre of Fuel Consumed

Fuel Type	CO ₂ Emissions Per Litre of Fuel Consumed
Petroleum	2.5kg
Liquefied Petroleum Gas (LPG)	1.6kg
Diesel	2.7kg

(Australian Greenhouse Office, 2006e)

Fuel switching strategies need to consider a number of factors that impinge on the GHG emissions from different fuel choices, particularly the relative fuel (energy) efficiency of each fuel. Each fuel has a specific 'energy potential', which is revealed by how many kilometres a vehicle can travel per litre using a particular fuel type. Fuels with higher energy potential produce greater energy outputs than the same volumes of fuels with lower energy potential. For example, a comparison between diesel and LPG reveals that although diesel has the higher emissions emitted per litre, it may be a better choice environmentally due to its higher energy potential. To make up for the reduced energy potential of LPG, vehicles would need to consume greater quantities emitting more GHG emissions per kilometre traveled to achieve the same distance compared to a diesel engine (Australian Greenhouse Office, 2006e). As a variable affecting GHG emissions, the type of fuel consumed has a significant impact. But when considering the effect per litre, it is important to also calculate the efficiency of the fuel type per kilometre traveled for each transport mode. Hence articulating emissions per litre per kilometre traveled will assist in better determining which fuel type is most efficient.

The impact that fuel type will have on GHG emissions is dependent significantly on the evolution of fuel efficient technology, as well as introduction of alternative fuel sources such as ethanol into fuel composition. Policies and standards to alter the composition of fuel in favor of more environmentally friendly fuel types (i.e. LPG) will contribute significantly to the fuel quality of emissions.

6.2 GHG Efficiency of Motors

It is sometimes claimed in policy circles that if automobiles, particularly the passenger car, were more fuel efficient, then the transfer to more ecologically sustainable transport modes (i.e. trams, trains, buses, cycling) would not be as necessary to achieve a reduction in GHG emitted into the atmosphere. It is not the purpose of this report to discuss the merits of this argument, but to explore how technological innovations, if developed and widely utilized, could help achieve greater fuel efficiency of vehicles and therefore reduce the amount of GHG emitted into the atmosphere.

In Australia, advances in engine technology over the past 20 years have helped reduce the average fuel consumption per unit of maximum power output by 45 per cent (BTRE, 2002 in Bureau of Transport and Regional Economics, 2002b, p64). Such efficiency gains should have resulted in reduced vehicular fuel consumption, but this has not happened for several reasons, including the concurrent increase in vehicle power, potential for acceleration, and level of comfort. The extent to which greater fuel efficiency as a variable can reduce GHG emissions is of particular interest when thinking as well about driving behavior of the population within cities. People might be inclined to drive vehicles with larger 'fuel efficient' engines because the cost per VKT is lower because of improvements in fuel efficiency, a notion described as the 'rebound effect'⁹. This effect offsets any progress made through technology to reduce emissions. BTRE (2002b, p7) reports that, 'There has been little improvement over the past

⁹ The 'rebound effect' is the tendency for people to drive more when the fuel cost per kilometre decreases due to greater fuel efficiencies (Bureau of Transport and Regional Economics, 2002b, p66).

decade in the average fuel intensity of cars. Average VKT per car has probably not been altered markedly over the last ten years. The task (measured in terms of passenger-kilometres traveled) has been estimated to have not grown as much as car VKT, since the average occupancy rate has probably declined.'

6.3 Vehicle Occupancy and Public Transport Ridership Levels

Per capita GHG emissions in transport are influenced greatly by levels of vehicle occupancy. As a generalization, the lower per capita emissions from public transport are due to higher occupancy per VKT. For both private and public transport, therefore, per capita GHG emissions per kilometre can be reduced by greater occupancy rates in private vehicles and increased ridership in public transport (with all other factors remaining the same). According to the BTRE (2002b), the average private car occupancy rate in Australia is approximately 1.1 persons and there has been a trend of declining occupancy, which BTRE attribute to increasing income and declining real travel costs (Bureau of Transport and Regional Economics, 2002b, p11).

Greatest GHG reductions accrue from strategies that accomplish a shift from the use of private vehicles to public vehicles. A population that relies on public modes of transport as their primary means of travel will emit less GHG per capita than those using private vehicles running on fossil fuels. According to Urban Ecology Australia¹⁰, by shifting passenger transport from private cars to public transport vehicles, urban traffic density will be reduced with resultant reductions in fuel use and GHG emissions, and increased amenity of urban space (Urban Ecology Australia, 2006). In other words, increased use of public transport confers the benefit of increased energy efficiency on the entire urban transport system, including motor vehicle usage. Public transport offers a means to provide urban mobility services with more efficient use of resources than private transport and can better utilize the existing transport infrastructure.

6.4 Population

Urban population levels in the major cities are strongly correlated with total VKT and total GHG emissions, and other demographic factors also influence urban transport, such as the historical association between population growth and rising GHG emissions (Turton, 1999). This rise, in conjunction with household income increases (see the next section on GDP), has contributed to the increase in vehicles owned and VKT. Within cities, demographic factors can influence transport in other ways, such as the affect of an aging population and socio-economic status on the ownership of private vehicles and the use of public transport.

The most comprehensive population forecast for each Australian capital city from 1990 to 2020 is the one provided in the BTRE 2002 data set (see Appendix F). These population estimates are based on AGO data assumptions and ABS long-term projections (Bureau of Transport and Regional Economics, 2002a, p236). Actual population figures are provided for 1990 to 1999, and forecast figures are provided for 2000 to 2020. The population figures provided by the BTRE 2002 report were used to calculate GHG emissions per mode of transport per capita for each capital city (See Appendix I). Sensitivity analysis in the 2002 BTRE report forecast the impact that both high population growth and low population growth have on GHG emissions relative to the business-as-usual scenario.

¹⁰ Urban Ecology Australia is a United Nations accredited non-profit, non-government, educational association based in Adelaide, South Australia. The objective of Urban Ecology Australia is to promote people in nature friendly urban settlements (Urban Ecology Australia, 2006).

6.5 Gross Domestic Product

Gross Domestic Product (GDP) has in the past shared the same positive correlation with GHG emissions as population. This correlation suggests that with an increase in GDP, and hence household incomes, car ownership and VKT rise as well. Economic growth has therefore been a strong variable in understanding increases in GHG emissions from urban transport. However, according to sensitivity analysis generated by the BTRE 2002 report, the rate of emissions growth is expected to be above that of population growth – averaging about 0.7 per cent per annum – but below the forecast rate of GDP growth averaging about three per cent per annum (Bureau of Transport and Regional Economics, 2002a, p17).

The apparent slower rate in GHG emissions growth relative to the strong growth in GDP can be explained through the concept of 'saturation'. Per capita car travel in Australia has been following a logistic (saturating) curve against real per capita income (GDP). Hence, as income per person increases, personal car travel per person also increases, but at a slowing rate over time until 'saturation' occurs resulting in no further increase in passenger travel (Gargett, 2005, p2). Further analysis provided by Gargett et al (2005) suggests that cars make up the largest component of the traffic stream, a result of rising income levels enabling people to own and drive passenger vehicles with greater financial ease.

The BTRE 2002 Report contains data, forecasts and scenarios helpful to identify future trends. BTRE provides business as usual GDP growth assumptions for Australia (Appendix F) considering both a higher and lower economic growth rate than the predicted business as usual (Bureau of Transport and Regional Economics, 2002a, p31). An average GDP growth of approximately three per cent per annum from 2000 to 2020 is considered. These figures are based upon estimates derived by the AGO (Bureau of Transport and Regional Economics, 2002a, p237). Interestingly, the projections forecast that saturation will occur as GDP increases (with the exception of freight which is heavily influenced by an increase in GDP), suggesting that the correlation between GDP and GHG emissions may be weakening.

6.6 Urban Form

City structure has a strong influence upon transport behavior patterns, making it a key variable in GHG emitted per mode of transport per kilometre traveled. Employment and residential densities (and the travel between home and work, i.e. journey to work) will be included as a variable in the analysis of urban form. According to Naess (2004), congestion volumes on roadways, a feature of a strong passenger car-based culture, has helped to make public transport a more attractive commuting option (Naess, 2004, p165).

As part of the Commonwealth of Australia's strategy for long-term GHG mitigation, the Commonwealth has declared sustainable urban planning important in managing how people and goods are transported throughout the city (Commonwealth of Australia, 1998, p9). The layout of a city (i.e. the distribution of land uses and intensity of development) impinge on the efficiency of various forms of transport, route selection, and mode selection (Department of Natural Resources and Environment, 2002, 80), and the decisions by policy makers to focus public transport in some areas of the city rather than others. Additionally, distance traveled and transport mode utilized are influenced by the location of residents in relation to activity centers; design of subdivisions; and, availability and relative attractiveness of different transport modes (Department of Natural Resources and Environment, 2002, p80).

The urban form is of particular interest in the Australian context as Australian cities have comparatively low average urban population densities and are characterized by extensive suburban land use patterns that result in significant distances between locations (Department of the Environment and Heritage, 2005p, 18). As a consequence, the decentralized land use pattern in Australian cities is perceived to be contributing to the demand for more roadways increasing the reliance on private vehicle use (Department of the Environment and Heritage, 2005, p18), while public forms of transportation become 'too costly' to justify in low density areas.

The way in which cities are structured, including densities, dispersal of amenities, incorporation of green space, infrastructure and availability of transport services (including transit ways, bike lanes, trains, and trams), city layout (e.g. grid versus cul-de-sacs), and location of employment relative to residential neighborhoods, all contribute to urban form. Each acts as a variable contributing to VKT and the GHG emissions of the different modes of transport.

6.7 Fuel Price

High international prices for oil in the mid and late 1970s produced global economic recessions and created much uncertainty about security of supply. One effect was the great rise in the cost of operating motor vehicles, and a trend of increased consumer preferences for more fuel-efficient cars. After several decades of comparatively lower international oil prices, oil has again increased rapidly in price in recent years exceeding \$US75 a barrel in 2006, resulting in Australian petrol price increases. The retail price for petroleum was between 120-140 Australian cents a litre for the twelve months to September 2006 (although this is still one of the lowest prices in the OECD), up from around 80 cents in 2001 (see the Australian Institute of Petroleum, 2002).

Many of the public transport operators have reported that demand has increased, and attribute this trend to the rising cost of operating private cars. For example, although it stated that other factors in addition to rising fuel prices were influencing its customers, Melbourne's Metlink reported that combined bus, tram, and train demand grew by six per cent for the twelve months to June 2006 (*The Australian*, 2006, 'Petrol rises boost public transport use', 5 September). Train demand, which involves longer journeys, has increased most.

Higher petrol prices have placed downward pressure on the market for low-efficiency motor vehicles, although it will take some time to gauge the lasting extent of changes in sales and whether consumer preferences will 're-adjust' following the initial 'shock' of higher prices. Motor vehicle sales in the twelve months to August 2006 saw a fall in demand for large and medium cars, sports cars, and large four-wheel drive vehicles, and an increase in demand for light cars and smaller cars, trends consistent with consumer concerns about higher fuel prices (Federal Chamber of Automotive Industries, 2006).

6.8 Congestion

Congestion is not generally considered an independent variable, but as a situation that results when a number of factors increase the number of vehicles traveling on a particular road system. Traffic engineers have developed several measures of congestion, such as the extent to which road lanes are occupied, and the level of service being provided. It is a variable influenced by urban form, transport behavior, demand management policies, vehicle occupancy, and other factors, and can be assessed based on total vehicles per kilometre of road and car kilometres per kilometre of road (Kenworthy, 1999, p546). Congestion is a significant influence on vehicle emissions because fuel consumption per vehicle (litres per 100 kms) under congested traffic conditions is approximately twice that under free-flowing conditions (Bureau of Transport and Regional Economics, 2002a, p126).

Some urban and transport planners consider that congestion is an indirect cost to the motorist (principally through increased trip times), and can serve as a means to discourage car use – i.e. increased costs of travel reduces travel demand. However, congestion imposes direct social and environmental costs on urban areas, not only through increased GHG emissions, but also through such effects as air pollution and damage to human health. Policies to respond to traffic congestion that advocate increasing road capacity are often criticized for creating 'induced demand' (or 'induced traffic'), whereby increased capacity attracts more drivers. Few planners are likely to advocate expansions of road capacities as a stand-alone measure, particularly as a cost-effective means of reducing GHG emissions.

Urban design is particularly important, as the design of the city will affect congestion levels. Therefore, rethinking the design of cities and the relationships that people have with the built environment can reduce congestion levels, hence reducing GHG emissions. Sustainable travel behaviour within the city can be encouraged with greater emphasis on density around transport hubs, mixed-use planning, and better integration of alternative forms of transport.

6.9 Managing Demand for Transport

Building and reorienting transport infrastructure to support sustainable forms of transport alone will not be sufficient to encourage modal shifting. Required as well is an emphasis on behaviour change. Managing travel demand through incentives favoring sustainable transport, and disincentives against passenger cars, in addition to managing travel to reduce kilometres traveled will help promote a reduction in GHG emissions.

Establishing and enforcing policies that encourage the adoption of sustainable forms of transport is one such means to encourage a modal shift. Policies have included road pricing, increase in parking cost, subsidizing public transport, increased petroleum taxes, and car-free (or low car-access) zones. Each of these policies, on their own, can be considered a variable to promote behaviour change towards more sustainable forms of transport. Organizations including BTRE have used hypothetical policy scenarios to forecast the effects of such demand management variables on transport GHG. Each policy variable when implemented is expected to encourage a modal shift towards more sustainable forms of transport.

Table 14: Assessment of Variables which Impact GHG Emissions

Organization	Variable	Scope	Forecasts and Scenarios	Notes
ECONOMIC VARIABLES				
BTRE (2002a)	Fuel price	Does not break down emissions per mode or per city.	High and low projection scenarios for fuel intensity. Provides insight into 'business as usual' forecasts as well as optimistic and pessimistic scenario possibilities.	Generic forecasts are conducted using two long-term price elasticities to predict emissions in gigagrams for 2010 and 2020. Providing analysis for high and low projections, the base from which these projections are made articulate the price of oil at \$US29.57 per barrel based on 2001 figures (Bureau of Transport and Regional Economics, 2002a, p40). Price of fuel per barrel has since risen substantially to 50 and even as high as 70 dollars per barrel suggesting that the \$US 29.57 base figure is out of date.
BTRE (2002a)	GDP	Does not break down per city or per mode of transport.	High and low projection scenarios assuming a high and low economic growth rate.	GDP forecasts for 2001 to 2020 for all of Australia. Considers the saturation effect implying that GHG emissions will not grow at the same pace as GDP.
Kenworthy and Laube (1999)	GDP	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Refutes notion that automobile use will naturally increase as GDP rises. Suggests that stronger variables to consider are the priorities in the provision of transport infrastructure and economic policies to restrain its growth.
Kenworthy and Laube (1999)	Vehicle owner-ship	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Weak variable when assessing level of GHG emissions relative to vehicle use. There is a vehicle ownership saturation point. Rise in GDP, may allow people to own more vehicles, but it is the use (VKT) which increases.
SOCIAL VARIABLES				
BTRE (2002a)	Population	Provides figures for each mode of transport for	High and low projection scenarios. Business as usual and optimistic and	Forecasts are made per mode of transport per city over a period from 2000 to 2020. These numbers can be utilized to generate emissions per mode of transport per capita.

		each city from 1990 to 2020.	pessimistic scenario projections.	
Gargett and Gafney (2005)	Vehicle Kms Traveled (VKT)	VKT values are provided for each mode of transport for each city.	Forecast available for 2020 for the passenger vehicle for each capital city. The figures are obtained from the BTRE 2003 report.	VKT per person for each city can be multiplied by the city population to obtain total VKT for each city. The purpose is to see the per cent increase of VKT as a result of the population increase. Figures provide evidence of the saturation effect.
TECHNOLOGICAL VARIABLES				
Australian Greenhouse Office (2006f)	Fuel Type	Does not break down per city or per transport mode.	No forecasts or scenarios are provided for this variable.	Provides figures for CO ₂ emissions in kg per litre of fuel consumed for petrol, LPG and diesel. Energy potential of each fuel type is not addressed.
CSIRO (2005b)	Fuel Type	Figures are limited to trucks and buses and are assessed at the urban/non-urban level.	Forecasted future emissions for a number of fuel types.	This study provides a full life-cycle analysis of fuel types including end-use emissions and also extraction, production, transport, and distribution. The comparison between fuel types is made on the basis of both the amount of emissions per energy used and the amount of emissions per kilometre of distance traveled. Data is derived from Apelbaum figures.
BTRE (2002a)	Fuel Efficiency	Provides data on passenger vehicles and does not break down per city.	Provides base case scenarios for 2000 to 2020.	Forecasts are provided for rate of fuel use (L/100 km) for passenger cars, National Average Consumption is a sales-weighted average of new passenger cars.
STRUCTURAL VARIABLES				
Kenworthy and Laube (1999)	Urban Form: Density	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Urban density is a variable. Density generally surrounds transit nodes and urban sub-centers. Strong correlation exists between reduced motor vehicle travel and higher urban densities.
Kenworthy and Laube (1999)	Urban Form: Journey to Work	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Strong variable to explain congestion on roadways during peak hours. Journey to work contributes greatly to VKT.
Kenworthy and Laube (1999)	Congestion	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Congestion is a variable of speed on roadways and can be measured by total vehicles per kilometre of road and car kilometres per kilometre of road. Speed between modes helps to determine, transportation choice, influencing the level of GHG emissions emitted. Speed of transit has a positive relationship with high urban densities.
Kenworthy and Laube (1999)	Vehicle Use (VKT)	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Strong variable. Correlated strongly with urban form (low vs. high density) and GDP. However, use is affected by the saturation point.
POLICY VARIABLES				
Kenworthy and Laube (1999)	Managing Demand: Parking Provision	Breaks down for each city but not per transport mode.	There was no forecast or scenario provided.	Amount of land allocated for parking in a CBD acts as an indicator for city priorities in relation to transportation. Indicated by spaces per 1000 jobs, this indicator can be misleading if job growth is not factored in as well.
BTRE (2002a)	Managing Demand: Optimal Road Pricing	Does not break down per mode or per city.	Breaks down emissions per year for 2000 to 2020 for all eight capital cities combined.	Congestion reductions through optimal road pricing using Intelligent Transport Systems (ITS) to charge road users for the costs resulting from their travel decisions.

7.0 Potential for Future Monitoring of Emissions

Based on the analysis undertaken for this report the BTRE appears to be the organization most likely to provide consistent and on-going data collection and evaluation of the transport sector. Perusing the BTRE website, a number of research programs related to better understanding of the transport sector and its impact on GHG emissions are currently being undertaken for 2005-2006. Some of the most notable projects are listed in Table 12.

Table 15: Current Projects Undertaken by BTRE

Project Title	Primary Question
Australian Transport Statistics 2005	What are the factual trends in usage of aviation, shipping and other transport modes?
Analysis of the ABS Survey of Motor Vehicle Use	What can analyzing the Survey of Motor Vehicle Usage unit record data tell us about improving the survey's accuracy?
Freight Info 2004 Database	What were the inter-regional freight flows in Australia by mode in 2003-04?
Standing Committee on National Transport Data Framework Project	What are the opportunities for Commonwealth/State land transport data sharing?
Freight measurement and modeling in Australia	What do we know about freight flows in Australia and how to model and forecast them?
Passenger Movement between Australian Cities	What will growth be to 2025 in passenger movements by mode between Australian capital cities?
Modeling for Better Transport Planning Workshop	What are the main issues and challenges in improving land transport modeling and analysis in Australia?

(Bureau of Transport and Regional Economics, 2006a)

Additionally, the BTRE website provides links to transport statistics generated by transport authorities across Australia, which assess petrol prices, petrol sales, rail transport activity, motor vehicle taxes and charges, automotive diesel sales, and rail freight movements across time and geographic region in Australia. Therefore the potential to monitor GHG emissions from the transport sector is very much a possibility, particularly if referencing the BTRE for such information.

However, if there is to be a serious effort to reduce greenhouse emissions from transport a comprehensive and co-ordinated effort will be required involving action at every level of government. We now turn to such an approach.

8.0 Stabilizing Greenhouse Emissions from Transport: Portfolio Thinking

Pacala and Socolow (2004) propose 'stabilization wedges' to address the climate problem. To paraphrase these authors, the 50 year trajectory (2000-2050) can be represented on a graph with time on the horizontal axis and fossil fuel emissions on the vertical. The space between the line representing *business as usual* emissions (tending upwards) and the line representing desired emissions for stabilization (flattening and then turning down) make a rough triangle: the 'stabilization triangle'.

This triangle can be divided into a series of wedges representing mutually reinforcing spheres of action. Options for 'stabilization wedges' proposed by the authors include: improved fuel economy, reduced reliance on cars, more efficient buildings, improved power plant efficiency, substituting natural gas for coal, storage of carbon captured in power plants, hydrogen plants, and synthetic fuel (from coal) plants, nuclear fission, wind electricity, photovoltaic electricity, renewable hydrogen, bio-fuels, forest management, and management of agricultural soils. They point out that all of these options can be employed today (and most are) with known and tried technology, and that, while none is 'a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used' (*ibid*: 968).

Pacala and Socolow focus on technical change. It seems unlikely, however, that technical change alone can be relied upon to produce the desired results without concomitant change in urban life. In the transport policy sector a change will almost certainly be required in existing patterns of urban mobility. Such change can be part of the portfolio approach advocated by these authors, but the policy changes required to produce change in patterns of urban mobility

will also require institutional change, which is a subject for further investigation. Plainly action is required at every level of government, but some actions can be initiated at local level.

'Portfolio' thinking suggests that government strategy should not be limited to manipulating the market through emission caps and carbon trading. More active interventions are needed at the city level. The options mentioned above suggest a first sub-division of the task to create an *urban wedge*, an *energy wedge* and an *agricultural wedge*. Of course these wedges interact: for example the global bio-fuel crop will compete for land in some places with the food crop, and bio-fuel policy interacts with transport policy.

These interactions are critically important, and in some areas there are greater doubts about the science of emission reduction than about climate change itself: will the proposed action actually reduce CO₂e (equivalent) emissions in one sector (say, vehicle technology) without interfering in other policy goals (e.g. food security) or with emission levels in another sector (electricity production) ? What will be the economic cost (or cost saving) of reduction strategies? A significant fraction of scarce research funds needs to be devoted to answering such questions. Nevertheless, an urban transport 'stabilization wedge' can be postulated.

If mobility is considered a good, its extremely skewed distribution throughout the world means that justice demands a fairer distribution. Assuming that the distribution of mobility roughly corresponds with the distribution of GHG emissions, a much larger than 80% reduction in emissions from transport is necessary on the part of the developed world to allow poorer countries to increase their mobility. Moriarty and Honnery (forthcoming) point out that, globally, car ownership is expected to increase by a factor of five by 2050 meaning that a reduction of CO₂e emissions per passenger kilometre traveled must fall to one twenty fifth of current levels, a 96% reduction.

Table 16: Options for cumulative reduction of GHG emissions from urban transportation

Action	GHG Reduction	Reduction Factor (cumulative)
Travel 'business as usual' (current)	1.0	1.0
Travel demand management Reduce travel demand by 30% (greater use of work from home using communications technology; more efficient logistics etc.)	0.70	0.70
Travel carbon efficiency Shift 30% of journeys to low or non-GHG modes (low carbon public transport, cycling, walking for short journeys)	0.70	$0.70^2 = 0.49$
Vehicle occupancy Increase vehicle occupancy by 30% (more people per vehicle in private and public transport),	0.70	$0.70^3 = 0.34$
Vehicle fuel efficiency Improve fuel efficiency for travel by 30% (use of low powered engines for cars, lightweight cars)	0.70	$0.75^4 = 0.24$
Fuel GHG performance Obtain 30% energy for individual travel from renewable or low carbon sources	0.70	$0.75^5 = 0.17$ (circa 83% reduction)

In the above Table 16, five options for a putative 30% reduction in each are combined to produce an overall reduction of around 83% on the *business as usual* trajectory. These factors might in some cases have potential for greater reductions and in some cases less, but in combination they achieve what would probably be beyond any single policy element. The total

reduction of 83% of current emission levels from transport in a developed economy such as Australia is not enough to compensate for growth of mobility in developing nations, so further large scale reductions would be required after 2050.

Let us now consider the prospects for change in somewhat greater detail.

8.1 Prospects for change

Travel demand management

A thirty per cent reduction in travel looks like a difficult proposition in the light of the continuous *growth* of travel in the developed world over the last fifty years. In Australia total metropolitan¹¹ road travel by all types of road vehicles has been projected to rise by 41 per cent between 2002 and 2020 (Gargett and Gafney, 2006). However the task may not be impossible given the right mix of policies. A 30% reduction in total kms traveled by road from 2007 means returning to something like the total for 1993, from about 135 billion kms to about 94 billion kms. A 20% reduction means returning to 1998. Was Australia so much worse off then? Comparing Melbourne with European cities shows that Melbournians take 27% more trips per day (all trips by all modes) than the average for seven European cities and 40% more trips than Londoners (see Table 17). These figures suggest strongly that economic prosperity is not necessarily linked to mobility. It should be possible with the right mix of policies to bring Melbourne nearer the average for prosperous European cities.

Gargett and Gafney (2006) do not consider the problem of climate change at all, or the potential for travel demand management to help solve it. The potential for remote communication to replace at least some of the daily journeys from home to work – a pattern stemming from 19th century factory and 20th century office practices – has scarcely yet been tapped. Improved freight logistics designed to reduce trips instead of reducing storage at depots can also play a role. ‘Just in time’ delivery systems place a great many more vehicles on the roads at less than full load, and is only really economically viable because the market price of travel is so low. Travel reduction could attain its own momentum once the price of travel is increased to reflect the true costs of global warming.

**Table 17: Mobility and Modal Split in Melbourne and European Cities
(Source: UITP, *Mobility in Cities Database 2001*)**

Cities (2001)	Daily trips per inhabitant	Daily mechanized trips per inhabitant	% of daily trips on foot and by bicycle	% of daily trips by private motorised modes	% of daily trips by public transport
Melbourne	3.72	3.09	18	76	6
Amsterdam	2.9	2.15	51.4	33.9	14.7
Brussels	2.82	2.08	27.5	58.9	13.6
Copenhagen	3	2.44	39	48.9	12.1
Helsinki	3.1	2.41	29	44	27
London	2.65	1.86	31.1	50.2	18.8
Munich	3.2	2.3	37.5	40.6	21.9
Stockholm	2.77	2.07	31.4	47.1	21.6

Travel carbon efficiency

The next element is shifting as much as possible of the remaining travel to zero carbon modes: walking and cycling. Since most journeys in and around Australian cities are of less than five kms it seems that a large proportion of these journeys could be made on foot or bicycle

¹¹ Road travel in Australia’s large State capital cities.

provided that well constructed, safe foot and bicycle paths are provided. A comparison of Melbourne with prosperous European cities is again instructive. Melbourne stands out as being very different in modal split, with only 18% of all trips on foot or by bicycle compared with the average for the European cities in Table 17 of 35.3%. With the right mix of policies, and serious expenditure on walking and cycling – not just for recreation but as a mode of transport – it should be quite possible to achieve more than a 30% increase in trips on foot or by bicycle. In fact a 50% increase would bring Melbourne up to the lowest of the European cities, Brussels.

It has been argued that what makes Melbourne and other Australian cities different from European cities is gross residential density (Newman and Kenworthy, 1989). Australian cities have much lower densities than European cities. But density is likely to bear little causal relationship to the above two factors. The difference is much more likely to be cultural.

The next three elements in the portfolio are closely related. The aim is to maximize the travel possible with a given level of CO₂e emissions (Moriarty and Honnery, forthcoming). These authors posit that this measure is the product of three factors: The vehicle occupancy rate (pass-km/vehicle-km), the vehicular well-to-wheels (i.e. primary) energy efficiency (vehicle-km/MJ) and the primary energy available per unit of GHG emissions (MJ/kg CO₂e).

Vehicle occupancy

It seems difficult to increase the vehicle occupancy rate of private cars by very much. Moriarty and Honnery point out that negotiating trips with others greatly reduces the convenience of the private car: 'If, say, car occupancies were permanently required to double to around three persons per car, the nature of car travel, and its perceived benefits, would be profoundly changed. Timing and even destination of trips would have to be negotiated to fit in with the needs of others, often non-family members'.

Increasing the vehicle occupancy rate for public transport is likely to have a much greater effect than for cars. Although Melbourne has an extensive railway system, the main gains in occupancy rate are likely to come in the bus fleet. And as Moriarty and Honnery point out, globally most public transport usage is by bus. They argue that a fivefold improvement in occupancy rate could be achieved by a shift from private car to public transport use. The energy intensity of public transport can be considered to be 50% greater than private car transport with no change in the fuel mix. Combining these factors for a typical OECD public transport system in 2030 gives a 750% improvement in energy intensity¹². If the percentage of trips by public transport in Melbourne were to double – from 6% to 12%, more in line with the European average, this would give an energy efficiency gain of around 16% (or a 16% reduction of MJ per passenger km) by 2030.

Vehicle fuel efficiency

Recent European studies suggest that 65% to 80% energy efficiency gains are possible in car performance (Akerman and Hojer, 2006; Ramesohl and Merton, 2006). An even more optimistic report comes from MIT researchers who propose that an improvement is possible of up to 169% (cited in Moriarty and Honnery, forthcoming). These are for new vehicles only, but converting, say, two thirds of the entire Australian car fleet by 2030 seems feasible. Improved energy efficiency of vehicles translates directly into improved greenhouse performance – the less energy used, the less CO₂e emitted, all other things being equal. Even taking the least optimistic figure indicates that at least a 40% reduction could be achieved by converting two thirds of the Australian car fleet over the next 50 years. Improving the fuel efficiency of public transport, particularly the bus fleet, may reduce emissions by another 5%.

¹² Moriarty and Honnery write 'Akerman and Hojer (2006) assume a doubling of fleet efficiency at constant passenger loading is possible for both buses and trains by 2050 in Sweden. Here we assume that worldwide pass-km/MJ can be raised by a factor of 1.5 by 2030 for all public transport systems at constant loadings. For no change in fuel mix, pass-km/kg CO₂equiv would rise a similar amount. Thus a typical OECD public transport system in 2030 might be 7.5 (i.e. 5x1.5) times as CO₂equiv efficient as a present fully car-based one'. 750% improvement in fuel efficiency per km travelled equates to a reduction in emissions to 1/7.5 of the starting point.

Fuel GHG performance

What are the prospects for alternative fuels that can be easily stored and delivered, and emit less CO₂e in combustion per unit of energy than fossil fuels? A variety of fuels have been proposed for this role. Biomass based fuels can be regarded as emission-reducing, though they are not, as is sometimes claimed, carbon neutral. Burning fuel from biomass releases CO₂ into the atmosphere but the growth of biomass for fuel also absorbs CO₂. Such fuels include ethanol and bio-diesel, produced respectively from corn or sugar cane, and rapeseed oil. But these crops compete for agricultural land with food crops, the demand for which will grow as world population grows. Also, just as with food crops, cultivation requires energy and fertilizer, which usually comes from fossil sources, and water which, as the planet warms, will also become more scarce in cropping regions. Some authors argue that the fossil fuel energy inputs required for cultivation are not much less than the energy content of the resulting liquid fuel (Wald, 2007; Reijnders and Huijbrets, 2006). Ethanol made from cellulosic plant matter may give a better net energy return, but is not yet in production. In the USA the production of cellulosic ethanol is only expected to rise from 2.9% of total fuels to 6.5% by 2030 (EIA, 2007).

Then there is electricity to convert directly to traction via electric motors, or to produce hydrogen via electrolysis which can then be burned in the engine. Excitement about the 'hydrogen fuel cell car' or the 'hydrogen economy' seems to be generated by the fact that burning hydrogen produces no carbon emissions. This neglects the fact that hydrogen has first to be produced using electricity or through fuel cells which usually employ fossil fuel. Hydrogen is a means of storing energy, and in this respect it can be compared with the more traditional electric battery. Moriarty and Honnery report that plug-in hybrid vehicles, using electricity from the grid stored in batteries plus efficient fossil fuelled engines to extend the range of the vehicle, are likely to be four times more greenhouse-efficient than vehicles powered by hydrogen fuel cells with hydrogen produced by electrolysis (Romm and Frank, 2006; Romm, 2006; Van Mierlo, Magetto and Lataire, 2006)

Both private individualized transport (cars) and public transport vehicles can run on electricity produced by renewable energy. Such energy can be produced by sunlight (photo-voltaics), wind or wave power, nuclear energy or coal whose carbon emissions have been captured and prevented from release to the atmosphere. The prospects for a larger proportion of energy being produced in future from renewable sources are difficult to predict, but Moriarty and Honnery point out that, far from increasing, the share of renewable energy in the global energy production total is on track to fall by 2030.

Railways and trams in Melbourne are powered by electricity produced from lignite, or 'brown coal' which has the highest CO₂e emissions of any solid fossil fuel. So, perhaps paradoxically in this case, some improvement in emissions can be expected over the next thirty years with the introduction of more efficient power stations and carbon capture and storage. For individualized transport a more hopeful and less distant prospect might be battery or plug-in hybrid vehicles charged from electricity produced and stored in the place of residence from roof mounted photovoltaic arrays. An Australian invention for increasing both efficiency and flexibility of photovoltaics (sliver cells) was recently reported by the Australian Broadcasting Authority 'Catalyst' TV program.

The general conclusion must be that we do not know yet whether a 30% reduction in emissions will be possible from new and changed fuels in the next 30-50 years. These technologies have to be placed in the realm of the speculative future, not the present.

The foregoing discussion has examined the potential of benign change in transport to reduce greenhouse emissions by the necessary 80% or more in the context of Melbourne, Australia. The discussion has proceeded from the easiest to the most difficult routes to follow to achieve this goal.

8.2 What Can Melbourne City Council Do?

Local government has limited scope for action. Yet there are direct actions that the City of Melbourne could take which would move towards a less greenhouse gas intensive transport

system. The most effective actions lie in the first two categories of the urban transport stabilization wedge, Travel Demand Management, and Travel Carbon Efficiency, for instance:

1. Find ways of reducing travel by substituting electronic communication for physical travel both for MCC employees and other workers in the city (especially the universities).
2. Encourage trip length reduction by encouraging increased residential development in the city.
3. Invest in much improved facilities to encourage the non-carbon modes of cycling and walking.
4. Link cycling and walking with access to public transport, and encouragement of tram priority throughout the city.

The question of policy options for Melbourne City Council, however, is beyond the scope of this report and requires much fuller investigation.

9.0 Conclusion

To conclude, four data sets - the Apelbaum Consulting Group 2006 data set, the Australian Greenhouse Office 2006 data set, the BTRE 2002 and 2003 data set, and the Kenworthy and Laube 1999 data set - on GHG emissions per mode of transport for each capital city in Australia have been identified. The BTRE 2002 and 2003 publication was selected as the most comprehensive document breaking down GHG emissions per mode of transport over a time period from 1990 to 2000 and providing forecast figures from 2001 to 2020. Tables provided by the BTRE on emissions per transport mode for each city, as well as figures on population provide the base from which per capita and per kilometre traveled figures could be derived.

In the second part of the report major variables influencing transport sector GHG emissions were identified, as well as information available on these variables and their potential to aid in forecasts of future trends under different conditions. The report concluded with a discussion of a potential 'portfolio approach' to stabilizing greenhouse emissions from transport.

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APPENDIX A

PRIMARY AND FINAL ENERGY CONSUMPTION IN THE TRANSPORT SECTOR

APPENDIX B
SALES OF PETROLEUM PRODUCTS

APPENDIX C

**CAPITAL CITY CO₂ EQUIVALENT EMISSIONS FOR EACH TRANSPORT MODE PER
CAPITA**

APPENDIX D

FUEL CONSUMPTION RATES AND FUEL COMBUSTION EMISSION FACRTOR

APPENDIX E

**BUSINESS AND USUAL PROJECTIONS OF VEHICLE KILOMETRES TRAVELED BY
TYPE OF VEHICLE FOR EACH CAPITAL CITY**

APPENDIX F
POPULATION AND GDP GROWTH PROJECTIONS

APPENDIX G

CONTACTS

Contacts

Transport Data Unit Queensland

P: 07 3834 2011 Web Site: www.transport.qld.gov.au

Spoke with Greg Brown. He advised me VKT is obtained from Household Travel Surveys, which looks at only passenger cars. Much of their data sources are obtained from Apelbaum Consulting Group and the ABS. Spoke with Brenden Hoyle and he referred me to the AGO data set.

Transport South Australia

P: 131 084 Web Site: www.transport.sa.gov.au/index.asp

Contacted Alan Perkins at 08 8204 8858. He said that the only data collected by Transport South Australia is from household travel surveys and that data is only on passenger cars. The last survey completed for Adelaide was in 1999. All other transport data is obtained by the Apelbaum Consulting Group report.

Ministry of Transport (NSW)

P: 02 9268 2800 Web Site: www.transport.nsw.gov.au/

They directed me to the Department of Energy, Utilities and Sustainability. They said that gathering data on emissions would not be in the ministry mandate.

Department of Energy, Utilities and Sustainability (NSW)

P: 8281 7778

They directed me to the Department of Environment and Heritage

Department of Environment and Heritage

Web Site: www.deh.gov.au

This is a national website, which links up with the AGO.

Public Transport Authority, Government of Western Australia

P: 08 9326 2000 Web Site: www.pta.wa.gov.au

Vic Roads

Web Site: www.vicroads.vic.gov.au

EPA Victoria

P: 03 9695 2722

Directed me to the AGO website, and to the EPA (1994) "Victorian Transport Externalities Study" report.

Australian Greenhouse Office (NGGI)

P: 02 6274 1888 Web Site: www.greenhouse.gov.au

Transport and Data Population Centre (NSW)

P: 02 9206 8611 Web Site: www.planning.nsw.gov.au

Data is available on their website on VKT, but nothing on greenhouse gas emissions. They referred me to the Australian Greenhouse Office for that data. The Centre said that they collect all their own data and process it themselves.