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Greenhouse gas emissions from Australian transport: projections to 2020

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Department of Infrastructure, Transport,
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GPO Box 501, Canberra ACT 2601, Australia
Telephone (international) +61 2 6274 7210
Fax +61 2 6274 6816
Email: bitre@infrastructure.gov.au
Internet: http://www.bitre.gov.au

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Foreword

This report presents the results of a Bureau of Infrastructure, Transport and Regional Economics (BITRE) study into recent trends in transport demand, energy use and resulting emission levels; and provides base case (or 'business-as-usual') projections out to 2020 of greenhouse gas emissions from the Australian transport sector.

These projections were prepared at the request of the then Australian Greenhouse Office (AGO)—now the Department of Climate Change (DCC)—and update previous BITRE results provided to the AGO, including: aggregate (unpublished) trend projections in August 2006; detailed sectoral projections in August 2005—published in the commissioned report *Greenhouse Gas Emissions from Australian Transport: Base Case Projections to 2020* (BTRE 2006a); and in July 2003, as an unpublished consultancy report, *Aggregate Greenhouse Gas Emissions from Australian Transport: Base Case Projections, Bottom-Up Approach, to 2020* (BTRE 2003a). Furthermore, these latest projections extend and update earlier BITRE publications dealing with transport sector greenhouse gas emissions—such as BTRE (2002a), *Greenhouse Gas Emissions from Transport: Australian Trends To 2020* (Report 107).

The following document describes the results of using BITRE's 'bottom-up' modelling approach to estimate base case projections of Australian transport activity (for the 2008 to 2020 financial years). Historical time series (for passenger transport tasks, freight movement tasks and emission levels) are provided from 1990 onwards. This summary report serves as a distillation of a large amount of numerical detail (covering the major inputs and latest outputs of the various BITRE projection models). This working paper is a reformatted version of a BITRE consultancy report that accompanied that numerical data, and was provided to the AGO in August 2007. The Department of Climate Change's latest report on transport sector emission projections (DCC 2008a), and the transport section of their recent paper summarising progress towards meeting Australia's Kyoto target (DCC 2008b), were both based on the BITRE study results.

The study was undertaken by Dr David Cosgrove, with assistance from Mark Cregan and Dr David Gargett. Ongoing BITRE research involves expanding the historical time series (on transport activity, energy consumption and emission levels) to include years earlier than the current 1990 starting point, extending the projections to cover longer-term periods than the current 2020 timeframe, and incorporating a greater range of input scenarios.

Gary Dolman
Acting Executive Director
Bureau of Infrastructure, Transport and Regional Economics
Canberra
December 2009

At a glance

- This paper presents the results of a detailed Bureau of Infrastructure, Transport and Regional Economics (BITRE) study into the modelling and forecasting of greenhouse gas emissions from the Australian transport sector. The study was undertaken in mid-2007, on behalf of the Australian Greenhouse Office (AGO), the federal body then responsible for administering programs under the Australian Government's climate change strategies. The Department of Climate Change (DCC, created December 2007), which now has responsibility for delivering these programs, has used BITRE projection results within their latest reports dealing with transport sector emission trends (DCC 2008a, 2008b).
- The (business-as-usual) projections in this paper are consistent with the reference case presented in *Australia's low pollution future: The economics of climate change mitigation* (Treasury 2008), and do not take account of future mitigation through the Australian Government's planned Carbon Pollution Reduction Scheme.
- Overall, emissions from the domestic transport sector in 2010 are projected, under the base case scenario (i.e. using 'business-as-usual' trend assumptions for most elements of Australian travel behaviour and demography, but allowing for the likely progress of meeting any greenhouse gas abatement measures to which Australian governments had already committed by mid-2007), to be around 48.1 per cent above the level for 1990, reaching 91.5 million tonnes of direct CO_2 equivalent (from transport energy end use). By 2020, BITRE projects such base case emissions to be around 70.3 per cent above 1990 levels (at 105.2 million tonnes of CO_2 equivalent).
- The scale of these forecast increases (which are similar in magnitude to previously released BITRE projections of transport emissions) points to the fact that Australian transport demand is highly dependent on underlying economic and population growth, and relatively inelastic with regard to fuel prices. For example, strong export growth tends to drive substantial growth in the movement of bulk raw materials.
- Within the aggregate forecast growth in domestic transport emissions over the projection period (at close to 1.6 per cent per annum, 2007 to 2020), emission totals for civil aviation, commercial road vehicles and rail energy end use (especially by dedicated freight railways) are all projected to have reasonably strong rates of growth (averaging above 2 per cent per annum). The passenger car fleet will remain the single largest contributor to total sector emissions (at around 47 per cent of 2020 domestic transport output), but is expected to exhibit a slower rate of growth (of around 0.86 per cent per annum between 2007 and 2020). Maritime sector (coastal shipping, ferries and pleasure craft) emissions are forecast to grow at around 1.2 per cent per annum (2007–2020).

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Executive summary

This report presents the results of a Bureau of Infrastructure, Transport and Regional Economics (BITRE) study into the detailed modelling and forecasting of greenhouse gas emissions from the Australian transport sector. The study was undertaken on behalf of the Australian Greenhouse Office (AGO), the federal agency formerly responsible for administering programs under the Australian Government's climate change strategies. The projection results (referred to herein as 'Base Case 2007' projections) were provided to the AGO in August 2007 (as a consultancy report under BITRE's then title—Bureau of Transport and Regional Economics, BTRE). The Department of Climate Change (DCC), which now encompasses the portfolio responsibility previously held by the AGO, has used BITRE's Base Case 2007 projection results within their latest reports dealing with transport sector emission trends (DCC 2008a, 2008b).

This study updates earlier projections provided to the AGO in previous years; including aggregate (unpublished) trend projections in August 2006, detailed modal projections in August 2005—published in the commissioned report BTRE (2006a), *Greenhouse Gas Emissions from Australian Transport: Base Case Projections to 2020*—and in July 2003, as an unpublished consultancy report; see BTRE (2003b), *Greenhouse Gas Emissions to 2020: Projected Trends for Australian Transport* (Information Sheet 21), for a summary of that year's study results.

These more recent projection studies extend and update base case projections of transport sector greenhouse gas emissions published in BTRE (2002a), *Greenhouse Gas Emissions From Transport: Australian Trends To 2020* (Report 107). BTRE (2002a) had in turn updated previous BITRE projections of transport sector emissions, published in BTCE (1995a), *Greenhouse Gas Emissions from Australian Transport: Long-term projections* (Report 88), and BTCE (1996a), *Transport and Greenhouse: Costs and options for reducing emissions* (Report 94). The greenhouse projection update studies subsequent to BTRE (2002a) have used results from another detailed study into the modelling of road vehicle emissions: BTRE (2003c), *Urban Pollutant Emissions from Motor Vehicles: Australian Trends To 2020*. Further revisions to such activity and emission estimates are generally prepared periodically, as part of ongoing BITRE research.

The emission projections are estimated using a 'base case' scenario (or 'business-as-usual'), for the 13 (financial) years between 2007 and 2020. The specific scenario, based on current trends, adopts what are considered the most likely future movements in travel behaviour, vehicle technology, economic indicators and demography, and also incorporates the likely impact of the greenhouse gas abatement measures that Australian governments had already fully committed to (by June 2007). That is, the effects of future abatement measures are not included in the Base Case 2007 projections, and would be the focus of further policy scenarios. In particular, the report does not take account of the Australian Government's planned Carbon Pollution Reduction Scheme (CPRS).

Therefore, possible effects of the CPRS on the transport sector are not included in the current base case (and for now remain the subject of policy scenario analyses).

As mentioned previously, this study was originally commissioned by the AGO and, following AGO specifications, the emission estimates presented in this report are generally given in terms of carbon dioxide (CO_2) equivalent 'direct' emissions. That is, most values are weighted totals (relative to an equivalent mass of CO_2) which include only the 'directly' radiative gases CO_2, CH_4 (methane) and N_2O (nitrous oxide), and do not include the indirect effects of gases such as CO (carbon monoxide), NO_x (nitrogen oxides) and NMVOCs (non-methane volatile organic compounds). Note that, for information, some order-of-magnitude estimates for trends in such indirect gases are provided in Chapter 5 (and the Appendix) of the report.

To comply with AGO/DCC sectoral emission inventory requirements, the emission estimates also generally refer to 'energy end use' (i.e. are from the direct combustion of fuel in the transport vehicles, and do not include further energy used to extract, refine or otherwise provide that fuel for vehicle use). However, for completeness and to aid consistent modal comparisons, estimates of full fuel cycle emissions from total domestic transport activities are also given in a latter section of the report (see Chapter 5 and Appendix tables A30 to A31).

Emissions from Australia's civil domestic transport sector in 2010 are projected, under the base case scenario assumptions (and the above classification/definitional details), to be around 48.1 per cent above the level for 1990, reaching 91.5 million tonnes of direct CO_2 equivalent (from transport energy end use). By 2020, BITRE projects such base case emissions to be around 70.3 per cent above 1990 levels (at about 105.2 million tonnes of direct CO_2 equivalent).

Within the aggregate forecast growth in domestic transport emissions over the projection period (at close to 1.6 per cent per annum, 2007 to 2020), emission totals for civil aviation, commercial road vehicles and rail energy end use (i.e. non-electric railways) are all projected to have reasonably strong rates of growth (averaging above 2 per cent per annum). The passenger car fleet will remain the single largest contributor to total sector emissions (at around 47 per cent of 2020 domestic transport output), but is expected to exhibit a slower rate of growth (of around 0.86 per cent per annum between 2007 and 2020). Emissions from the maritime sector (coastal shipping, ferries and pleasure craft) are forecast to grow at around 1.2 per cent per annum (2007–20).

Table ES1 and Figure ES1 summarise the BITRE base case projections for 2007 (where the table focuses on expected emissions growth to 2010 and 2020), along with an indication of the possible sensitivity range in the projections (assuming all the major input assumptions are varied simultaneously to either increase or decrease total emission estimates).

These latest BITRE projections exhibit a similar overall trend to the projections previously provided to the AGO (e.g. see BTRE 2006a and BTRE 2003b), with all the major sectoral contributions exhibiting reasonably comparable rates of projected growth. The aggregate emissions growth to 2020 is slightly lower in the updated projections, Base Case 2007, in comparison to the last published results (BTRE 2006a), with the 2020 domestic transport sector total of 105.2 million tonnes CO_2 equivalent being around 1 per cent lower than the BTRE Base Case 2005 projection endpoint result (see Figure ES2). The trend line for the current base case projection lies below that of Base Case 2005, partly due to higher oil price scenario values (both for present price levels and for future years).

In the absence of other factors, the significant increase in crude oil prices in recent years would have resulted in an even greater gap between the endpoint results of Base Case 2007 and Base Case 2005 (i.e. than that shown in Figure ES2). However, as well as the downwards pressure on the trend line from rising fuel prices, there were a variety of factors that served to push the emission estimates upwards to some extent—including:

- higher long-term projections of underlying economic or production activity (such as growth in Australian Gross Domestic Product or bulk export volumes) within the new base case, including significant increases to iron ore production projections by the Australian Bureau of Agricultural and Resource Economics (ABARE), and slightly higher projections of national population growth by the Australian Bureau of Statistics (ABS)
- continuing strong (trend) growth in motor vehicle sales and in air travel
- revisions to CO_2 emission rate values within the DCC's National Greenhouse Gas Inventory (NGGI) methodology (NGGIC 2007, 2006a, 2006b, 2006c, 2005).

Various other revisions to the underlying methodology (including model calibrations), activity data and scenario input assumptions also had effects on the emission estimates, but did not generally cause a consistent shift (i.e. either upwards or downwards) in the overall projection trend line. Values for both the historical emission aggregates and the projection results were influenced by these further methodological/technical revisions, which included:

- alteration or updating of emission factors for a variety of the non-CO_2 gas species assessed, both for the aggregate values within the NGGI methodology workbooks and for the disaggregate values within the detailed BITRE vehicle fleet emission models
- modifications or corrections to time series values for sectoral energy use by ABARE, based on their Fuel and Electricity Survey (FES) and the collation of petroleum sales data from the major fuel suppliers by the former Department of Industry, Tourism and Resources (DITR), where responsibility for the sales data now resides with the new Department of Resources, Energy and Tourism (RET, created December 2007)
- improvements to data availability for some of the smaller components of the fuel market (such as fuel consumption by military vehicles, sales of biofuels, and off-road use of automotive gasoline)
- revisions to various endpoints, for activity time series, that had to use preliminary data values in the previous base case
- some changes to BITRE's traffic congestion modelling processes, as part of a recent study into the estimation of avoidable social costs of urban road congestion (see BTRE 2007a).

Various data limitations make some elements of the modelling process quite approximate. For example:

- Parts of both the domestic aviation and shipping tasks are accomplished by international carriers, making the allocation of fuel used between domestic transport and international transport a generally complicated and fairly imprecise exercise.
- Even though quantification of some of the supplementary fuel use components noted above (e.g. military and off-road vehicle use, biofuel sales) has been improved recently, the precision of such estimates remains low, and would benefit from further improvements to data provision.
- Each of the three primary data sources that contributed to the estimation of Australian transport fuel use (specifically, DITR's monthly Australian Petroleum Statistics, ABARE's sectoral breakdown of total energy consumption by industry and fuel type, and the ABS Survey of Motor Vehicle Use) often exhibited some level of inconsistency and/or occasional discontinuities in times series, necessitating a variety of standardisation processes and trend-smoothing assumptions.

Though the accuracy of the estimation process, for aggregate transport emissions, is limited to a certain degree by such data problems (or relative paucity of reliable information), ongoing improvements to data collection and amendments to model formulations mean that these projection series are likely to form (analytically) the most robust transport base case yet published by BITRE.

Performance of BITRE transport demand models, even under their earlier formulations/calibrations, has been well demonstrated over time and, despite the gradual amendments, their overall structure has not altered greatly within the last decade or so. In fact, current levels of aggregate transport activity appear to be within a couple of per cent of values forecast for around 2007 in BITRE projections made in the mid-1990s.

Of course, predicting the future is generally a decidedly uncertain process—not only are the base case values strongly dependent on the assumed business-as-usual (BAU) trends in underlying prices and income levels (which could exhibit unforeseen levels of variation), but any policy scenarios (that attempt to estimate realistic future responses to tackling climate change) will also be subject to policy uncertainty. That is, the accuracy of policy scenario results (following on from this reference case scenario) will be dependent on:

- uncertainties concerning which climate change strategies are the most efficient or cost-effective
- which policies are the most likely to be implemented and exactly how will their specific abatement or adaptation measures be framed and administered (along with uncertainties concerning the precise economic and behavioural responses to such measures)
- the specific (policy-enabling) technologies that will actually be available in the future.

The level of future transport sector emissions will probably be strongly dependant on technological breakthroughs amongst a wide number of ongoing fields of research, including:

- battery performance and durability, for use in electric and 'plug-in' hybrid vehicles

- the treatment of woody waste and other lignocellulose to produce new generation biofuels
- improvement of solar-photovoltaic conversion efficiency and energy storage, or otherwise decarbonising the electricity supply—such as by 'carbon capture and sequestration'
- fuel cell cost-effectiveness
- the efficiency of hydrogen production using algal photosynthesis, solar-thermal or other renewable generation sources.

Assessing the likely degree of success, timing and scale of any such technical innovations will probably remain quite speculative for some time yet.

The greatest specific uncertainty concerning the base case projections is probably whether there will be any significant disruptions to oil supply during the forecast period, with any consequent increases in fuel prices impacting on transport activity levels.

Even though the recent high oil prices have served to dampen some elements of transport demand slightly, they do not appear to have made a large impact on aggregate Australian transport emissions (with total domestic transport emissions still rising during 2006, even with rapid fuel price rises). The prices appear to have been high enough to cause a temporary pause in the growth of total private vehicle travel, with annual sales of automotive gasoline (petrol) actually falling slightly during the 2006 financial year. However, during the early stages of 2007, total petrol sales started to return roughly to trend growth rates. The high crude oil prices, and economic downturn, during 2008 have since lead to a further pause in fuel sales growth—not taken into account here (since Base Case 2007 was prepared before these occurred). Yet over the medium term, 'business-as-usual' trends would be expected to gradually return to growth rate levels estimated herein.

High petrol prices also seem to have influenced recent vehicle purchase patterns by Australian motorists, with new sales of large passenger cars down by nearly 20 per cent in 2006 (i.e. new large sedan sales, with new four-wheel drive (4WD) 'All Terrain Wagon' (ATW) sales only decreasing slightly in 2006, and remaining close to 23 per cent of total passenger vehicle sales). Sales of small passenger cars and (highly fuel efficient) petrol-electric hybrid motor vehicles have been growing strongly, also probably influenced by the high fuel prices, with new small car sales increasing by about 20 per cent in 2006, and with new hybrid vehicle sales roughly quadrupling over the last three years.

Prices for petroleum fuels, in real terms, will likely remain substantially higher than the average over the 1990s, at least for the near-to-medium term. These (2007) projections are based on the assumption that high oil price levels eventually moderate somewhat—such that crude oil prices, in real terms, were forecast to return to a medium-term average of about US$50–55 per barrel after 2010 (see Appendix Table A20).

The latest (mid–2009) projections from the US Energy Information Administration have medium-term crude oil price forecasts considerably higher than these levels (that, in 2007, international energy agencies generally agreed as the most likely outlook). Work to incorporate these higher oil price forecasts (along with the effects of the global economic slowdown) into the BITRE base case projections is ongoing.

For some indication of the effects on the demand projections flowing fromrecent upward revisions to ABS (mid-range) population projections, see the BITRE-CSIRO appendix to the recent Treasury (2008) report on modelling climate change mitigation (BITRE and CSIRO 2008), and a recent conference paper on BITRE emission modelling (Cosgrove 2008). For an indication of the likely transport demand impacts of the economic slowdown, see a recent BITRE conference presentation (Cosgrove 2009).

The analysis has included a range of sensitivity tests, to help gauge the extent of the uncertainties inherent in the forecasting process (see Chapter 4 for the results of these tests). Note that the sensitivity scenarios given at the bottom of Table ES1 (and shown in Figure ES1) were provided due to a specific AGO request: to demonstrate how much the projection trend would be altered if all the major input assumptions are varied in combination, to yield the highest and lowest potential estimates (given the current base case model formulation). For example, the 'Low Scenario' is the result of running BITRE emission models using the AGO input specifications of low forecast economic growth, low population growth, a higher rate of fuel intensity improvements than the base case, as well as higher oil prices and lower future urban traffic congestion than in the base case. The 'High Scenario' and 'Low Scenario' trends are therefore supplied more as indicators of the models' dependence on the input assumptions, rather than necessarily as plausible scenarios for the future in their own right.

Given the wide range covered by the input variable settings for these two scenarios, it is highly likely that any realistic 'base case' scenario to 2020 (run on the current BITRE model framework) would fall well between these bounds. In fact, most choices of credible alternatives to the current base case settings (i.e. scenarios where the input parameter trends are varied to allow for uncertainties about future demographic or price trends, but not to the acute and synchronised extent assumed for the compound 'High Scenario' and 'Low Scenario' settings), would probably give results within about 10 per cent of the provided base case.

Basically, business-as-usual projections give an idea of likely 'latent' demand growth (that is expected growth in transport demand given current behavioural trends, and if fuel prices were to remain roughly stable, with no major structural change occurring within the transport sector or the Australian economy). Further scenarios (e.g. addressing different possible futures, especially depending on potential oil supply constraints or particular implementation of emission abatement policies), though important when considering longer term trends, are beyond the scope of this present study—and would have to be investigated by separate BITRE modelling/ projection studies.

Table ES1 Emission projections for energy end use by Australian domestic civil transport, BITRE Base Case 2007

Year ending June 30	*Cars*	*Other road vehicles*	*Air*	*Rail*	*Marine*	*Other*	*Total*	*Per cent change in total from 1990*
				(Gigagrams of direct CO_2 equivalent)				
1990	34 805	19 926	2 833	1 733	2 387	60	61 743	–
2007 (preliminary estimates)	44 503	29 970	6 867	2 413	2 176	94	85 803	39
2010 base case (BAU)	46 869	32 320	7 517	2 739	2 377	97	91 466	48
2020 base case (BAU)	49 750	41 251	8 894	3 343	2 537	107	105 151	70
2020 low scenario (combined sensitivity test)	39 954	32 517	7 263	2 959	2 244	89	84 153	36
2020 high scenario (combined sensitivity test)	57 875	49 232	10 364	3 858	2 866	121	123 598	100

Notes: CO_2 equivalent emission values include only contribution of direct greenhouse gases (CO_2, CH_4 and N_2O). Gigagrams = 10^9 grams, equivalent to thousand tonnes.

BAU business-as-usual.

Energy supply emissions are not included here (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included here (i.e. CO_2 emissions from the combustion of biofuels are excluded from these table values).

The base case projections allow for the likely effects of Australian government policy measures (aimed at abating emissions from the transport sector) that had already been put in place, by mid-2007.

The 'high case' projections consist of the highest level of emissions likely without major structural change to the Australian transport sector (under a model sensitivity scenario that combines the effects from changes to several major input settings).

The 'low' case projections consist of the lowest level of emissions likely without major structural change to the Australian transport sector (under a model sensitivity scenario that combines the effects from changes to several major input settings).

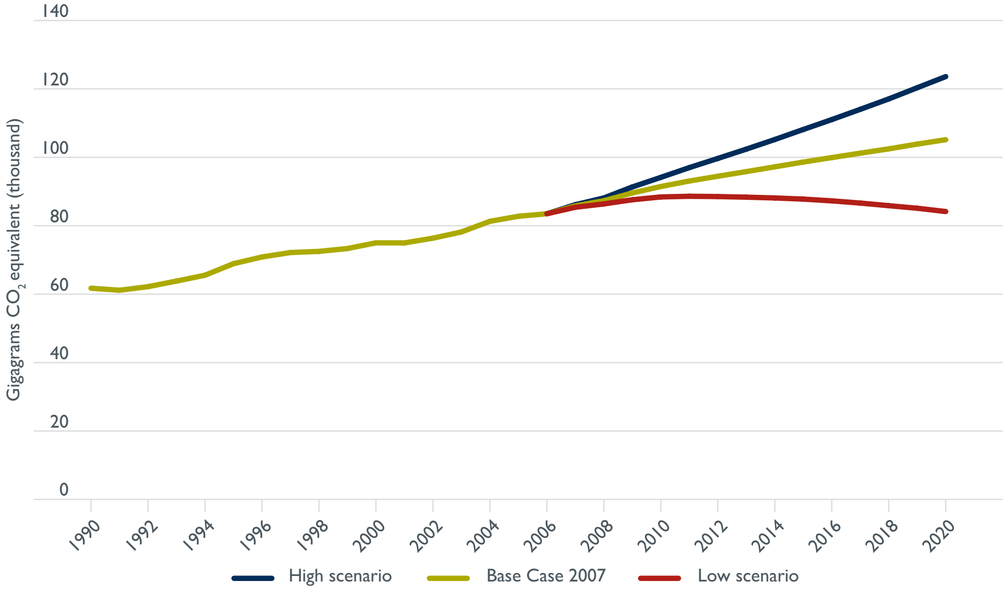
'Air' refers to total civil domestic aviation (i.e. including general aviation, but excluding military aircraft).

'Marine' consists of emissions from coastal shipping (which includes some fuel consumed by international vessels undertaking a domestic freight task), ferries and small pleasure craft (and excludes fuel use by military and fishing vessels).

'Other' refers to a rough estimate of emissions from unregistered off-road motor vehicles used for recreational purposes (such as trail bikes).

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Figure ES1 Projections to 2020 of CO_2 equivalent emissions from Australian civil domestic transport



Notes: Emissions relate to energy end use, and include only direct greenhouse gases. Emission estimates exclude CO_2 released from the combustion of biofuels.

Gigagrams = 10^9 grams, equivalent to thousand tonnes.

The Base Case 2007 projections allow for the likely effects of Australian government policy measures (aimed at abating greenhouse emissions from the transport sector) that have already been put in place.

The High Scenario projections consist of the highest level of emissions likely without major structural change to the Australian transport sector (under a model sensitivity scenario that combines the effects from changes to several major input settings).

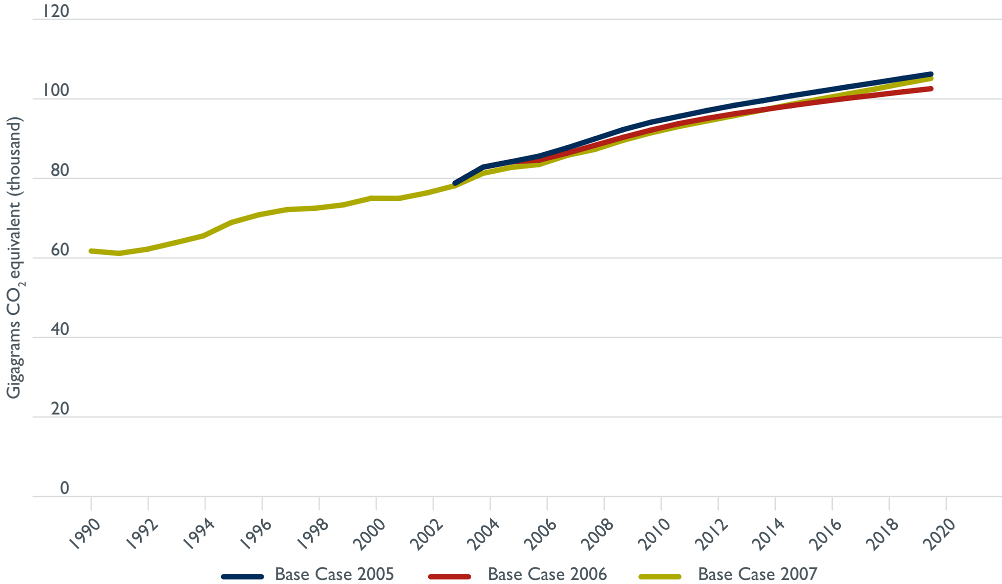
The Low Scenario projections consist of the lowest level of emissions likely without major structural change to the Australian transport sector (under a model sensitivity scenario that combines the effects from changes to several major input settings).

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

The latter part of the report (see Chapter 5 for more details) derives rough order-of-magnitude estimates for various components of the total transport greenhouse contribution not covered by the values given in summary Table ES1 (i.e. Kyoto Protocol 'accounting' totals for direct CO_2 equivalent emissions from civil domestic energy end use). In addition to the standard Base Case 2007 values (such as those plotted in figure ES2), for directly radiative emissions released from vehicle fuel combustion, Chapter 5 presents estimates that incorporate:

- indirectly radiative effects, such as due to ozone-forming emissions of gases like carbon monoxide and nitrogen dioxide (where ozone is a powerful direct greenhouse gas)
- the full fuel cycle (i.e. the inclusion of emissions released during transport fuel supply and processing, and during power generation for electric railways)
- international transport (allocating half of the emissions due to total fuel use by international shipping and aviation travelling to and from Australia)
- military transport fuel use

Figure ES2 Comparison of updated BITRE Base Case 2007 transport projections with previous aggregate base case results



Notes: Emission estimates relate to energy end use, and exclude CO_2 released from the in-vehicle combustion of biofuels.

Gigagrams = 10^9 grams, equivalent to thousand tonnes.

Totals include only direct greenhouse gases (i.e. do not include the indirect, and difficult to quantify, average warming effects of other gas species such as carbon monoxide, nitrogen dioxide, volatile organic compounds and carbon soot particles).

See Appendix Table A28 for a summary of the previously unpublished Base Case 2006 results.

Sources: BITRE estimates, BTRE (2006a, 2003a, 2003b).

- energy used for the movement of oil and gas by pipeline
- full transport system or life cycle effects (i.e. extra emissions caused by transport vehicle manufacture and disposal, and by transport infrastructure construction and operation).

The resulting BITRE estimate for the aggregate radiative forcing contribution of all Australian transport activity (under the above inclusions) is approximately 168.4 million tonnes for 2007. This value encompasses total CO_2 equivalent emissions (direct and indirect effects), for the Australian transport sector's energy use (domestic and international, using the fuel allocation detailed above) on a full transport system-cycle basis; with the level projected to increase by close to 25 per cent by 2020, to about 210.2 million tonnes (total CO_2 equivalent). Allowing for the additional effects of fugitive halocarbon releases from motor vehicle air conditioners raises the 2007 estimated total to about 174 million tonnes and the 2020 total to about 215 million tonnes (of total CO_2 equivalent emissions).

Such order-of-magnitude estimates for complete transport sector contributions to the anthropogenic greenhouse effect are around double Kyoto-accounting totals (for domestic end use, direct CO2 equivalent, such as given in Table ES1), and are projected to follow a slightly different trend into the future. Though these more comprehensive aggregates are only 'ballpark' estimates, their differing levels (and projected growth patterns), from the standard inventory accounting totals, serve to prompt the observation: that the appraisal of emission abatement measures could be affected if solely changes in direct end use emission levels are used in the assessment process, rather than also considering the total effects over the full transport system and its energy supply processes (including emissions of all relevant gas species, from all relevant sources).

Chapter 1 Aggregate base case projections

This report presents projections to 2020 of greenhouse gas emissions from Australian domestic (civil) transport. The underlying projections of vehicle fuel consumption are derived from BITRE base case projections of transport demand, and the consequent levels of vehicle activity (allowing for differing vehicle operating conditions for metropolitan and non-metropolitan travel).

This work extends and updates base case projections of transport sector greenhouse gas emissions published in BTRE (2002a), *Greenhouse Gas Emissions From Transport: Australian Trends To 2020*, (Report 107) and subsequent projections provided to the Australian Greenhouse Office (AGO), including: aggregate (unpublished) trend projections in August 2006, detailed modal projections in August 2005—published in the commissioned report BTRE (2006a), *Greenhouse Gas Emissions from Australian Transport: Base Case Projections to 2020*—and in July 2003, as an unpublished consultancy report (see BTRE 2003b, *Greenhouse Gas Emissions to 2020: Projected Trends for Australian Transport* (Information Sheet 21), for a summary of this study's results).

These 'bottom-up' base case projections have been developed using detailed BITRE modelling of Australian vehicle fleets, estimates of likely trends in new vehicle fuel efficiency, long-term projections of national and state populations by the Australian Bureau of Statistics (ABS) and Treasury projections of long-term economic growth. See the Appendix tables for details of the projection parameters, and the following BITRE studies for descriptions of the various modelling approaches: BTCE (1991) Working Paper 2, BTCE (1995a) Report 88, BTCE (1995b) Working Paper 22, BTCE (1995c) Working Paper 24, BTCE (1996b) Report 92, BTCE (1996a) Report 94, BTCE (1997) Working Paper 35, BTE (1998) Working Paper 38, BTRE (2002b) Information Sheet 18, BTRE (2002a) Report 107, BTRE (2003d) Working Paper 51, BTRE (2006b) Report 112, BTRE (2007a) Working Paper 71, and two consultancy reports prepared for Environment Australia—BTE (1999a) and BTRE (2003c), *Urban Pollutant Emissions From Motor Vehicles: Australian Trends To 2020*.

The specific base case scenario used for this study is based on assumed 'business-as-usual' (BAU) trends, and adopts what is considered the most likely future movements in travel behaviour, vehicle technology, economic indicators and demography over the coming years, and also incorporates the likely impact of the various greenhouse gas abatement measures that Australian governments had already put in place by mid-2007. Note that this particular base case specification does not include any possible effects due to the (yet to be introduced) Carbon Pollution Reduction Scheme.

National vehicle kilometres travelled (VKT), by all Australian vehicles, are projected to increase by around 1.7 per cent per annum between 2007 and 2020 (see Road section of Chapter 2 and the Appendix tables for details of the base case projections of Australian motor vehicle fleet activity), under the BAU assumptions.

The Base Case 2007 estimates of direct greenhouse gas emissions (CO_2 equivalent) from road transport are given, by vehicle type, in Table 1.1. Total road emissions from energy end use (excluding CO_2 emissions released from the combustion of biofuels) are projected to grow by about 21.6 per cent between 2007 and 2020 (around 1.5 per cent per annum), reaching a 2020 level of around 90.3 million tonnes of direct CO_2 equivalent (which is close to 65 per cent higher than the 1990 road total). Note that, for information, projections of road emissions are given by directly radiative gas emitted (i.e. for carbon dioxide, methane and nitrous oxide) for each vehicle type in Appendix tables, along with modal projections of emissions for the major non-CO_2 indirectly radiative gas species.

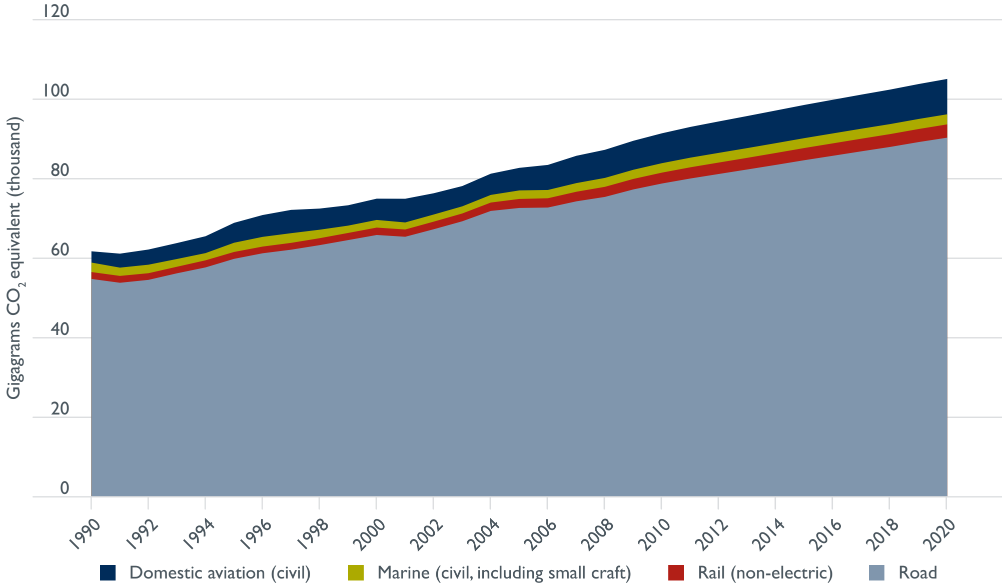
Total transport emissions to 2020 (direct CO_2 equivalent from energy end use) are presented by mode in Table 1.2, and the trends for the various direct gases are given in Tables 1.3 to 1.5.

Relative to the 1990 base year, emissions from the Australian civil domestic transport sector are projected (under the base case assumptions) to increase 48.1 per cent by 2010, reaching 91.5 million tonnes of CO_2 equivalent. By 2020, BITRE projects base case emissions to be close to 70.3 per cent above 1990 levels (at 105.2 million tonnes of CO_2 equivalent).

Referring to Table 1.2 and Figure 1.1, major points of note include:

- total transport sector growth, in direct CO_2 equivalent emissions (2007–2020), is projected to be 22.6 per cent (around 1.58 per cent per annum, similar to the road sector growth in emissions of 1.55 per cent per annum)
- aviation growth in direct CO_2 equivalent emissions (2007–2020) of 30 per cent (reaching a level of 214 per cent above the 1990 civil aviation total)
- direct CO_2 equivalent emissions from non-electric rail transport increasing by around 2.5 per cent per annum (2007–2020); and maritime sector (coastal shipping, ferries and pleasure craft) emissions forecast to grow at around 1.2 per cent per annum (2007–2020).

Figure 1.1 Base case projections of direct greenhouse gas emissions (carbon dioxide equivalent) for Australian transport



Note: Emission estimates relate to energy end use, and exclude CO_2 released from the combustion of biofuels. Gigagrams = billion grams, equivalent to thousand tonnes.

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 1.1 Base case projections of direct greenhouse gas (carbon dioxide equivalent) emissions for Australian road transport by type of vehicle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total road*
				(gigagrams of CO_2 equivalent)			
1990	34 805	7 704	5 099	5 629	1 245	249	54 731
1991	34 818	7 418	4 560	5 544	1 204	220	53 765
1992	35 478	7 637	4 393	5 592	1 175	220	54 494
1993	36 584	7 844	4 332	6 008	1 160	220	56 148
1994	37 505	8 038	4 483	6 187	1 197	217	57 627
1995	38 512	8 456	4 723	6 658	1 219	214	59 782
1996	39 006	8 730	4 999	7 003	1 235	208	61 181
1997	39 199	8 758	5 381	7 312	1 227	207	62 085
1998	39 466	9 238	5 461	7 626	1 242	199	63 231
1999	40 225	9 512	5 428	7 891	1 254	191	64 502
2000	40 923	9 744	5 517	8 148	1 261	192	65 784
2001	40 472	9 903	5 393	8 080	1 295	196	65 338
2002	41 440	10 365	5 586	8 358	1 283	199	67 232
2003	42 487	10 728	5 810	8 668	1 329	209	69 230
2004	44 168	11 157	5 937	8 993	1 352	227	71 836
2005	44 282	11 277	6 158	9 285	1 349	235	72 586
2006	43 759	11 403	6 440	9 508	1 331	246	72 687
2007	44 366	11 616	6 701	9 956	1 350	263	74 252
Forecasts							
2008	44 843	11 889	6 827	10 176	1 358	270	75 363
2009	45 998	12 166	6 968	10 478	1 366	275	77 251
2010	46 628	12 520	7 079	10 849	1 379	281	78 737
2011	47 041	12 890	7 155	11 236	1 389	288	79 998
2012	47 343	13 291	7 187	11 629	1 400	292	81 142
2013	47 648	13 669	7 219	12 021	1 421	298	82 275
2014	47 969	14 045	7 284	12 384	1 442	302	83 426
2015	48 316	14 428	7 349	12 740	1 467	308	84 608
2016	48 566	14 821	7 437	13 088	1 498	312	85 722
2017	48 783	15 250	7 511	13 448	1 535	316	86 844
2018	48 966	15 684	7 581	13 819	1 568	319	87 938
2019	49 240	16 129	7 691	14 176	1 604	326	89 165
2020	49 384	16 596	7 788	14 533	1 639	330	90 270

Notes: Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Gigagrams (Gg) = 10^9 grams, equivalent to thousand tonnes.

Emission estimates relate to energy end use, and exclude CO_2 released from the combustion of biofuels.

Sources: BTCE (1996a, 1995a), BTRE (2007a, 2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 1.2 Base case projections of direct greenhouse gas (carbon dioxide equivalent) emissions for Australian domestic civil transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total transport*
			(gigagrams of CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 556	1 676	2 142	3 817	62 191
1993	56 212	1 650	1 951	4 012	63 825
1994	57 693	1 783	1 817	4 245	65 538
1995	59 851	1 734	2 321	5 003	68 909
1996	61 251	1 687	2 445	5 491	70 874
1997	62 156	1 719	2 436	5 863	72 174
1998	63 305	1 747	2 135	5 318	72 504
1999	64 578	1 797	1 843	5 120	73 339
2000	65 862	1 863	1 926	5 352	75 003
2001	65 417	1 829	1 772	5 963	74 981
2002	67 314	1 914	1 792	5 347	76 367
2003	69 315	1 965	1 798	5 103	78 181
2004	71 926	2 109	1 923	5 337	81 295
2005	72 678	2 266	2 146	5 678	82 767
2006	72 780	2 338	2 085	6 303	83 506
2007	74 346	2 413	2 176	6 867	85 803
Forecasts					
2008	75 458	2 539	2 242	7 071	87 311
2009	77 347	2 643	2 307	7 293	89 589
2010	78 834	2 739	2 377	7 517	91 466
2011	80 096	2 822	2 425	7 733	93 076
2012	81 242	2 877	2 435	7 909	94 463
2013	82 375	2 933	2 449	8 070	95 828
2014	83 527	3 003	2 470	8 220	97 219
2015	84 710	3 066	2 488	8 356	98 620
2016	85 825	3 125	2 504	8 468	99 922
2017	86 948	3 180	2 513	8 576	101 217
2018	88 042	3 231	2 519	8 682	102 475
2019	89 270	3 286	2 527	8 787	103 870
2020	90 377	3 343	2 537	8 894	105 151

Notes: Emission estimates are for direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Emission estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways). Emissions exclude CO_2 released from the combustion of biofuels.

'Motor Vehicles' category includes all road vehicles, plus allowance for off-road recreational vehicles (which account for roughly 60–100 Gg per annum). 'Aviation' includes emissions from general aviation. 'Maritime' includes emissions from small pleasure craft and ferries. Emissions due to military transport are excluded.

Gigagrams (Gg) = 10^9 grams, equivalent to thousand tonnes.

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 1.3 Base case projections of carbon dioxide emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams CO_2)		
1990	53 689	1 714	2 315	2 803	60 520
1991	52 641	1 706	2 013	3 481	59 842
1992	53 276	1 659	2 070	3 779	60 783
1993	54 816	1 633	1 878	3 972	62 299
1994	56 180	1 764	1 742	4 203	63 889
1995	58 204	1 716	2 237	4 954	67 111
1996	59 500	1 669	2 357	5 438	68 964
1997	60 324	1 700	2 346	5 806	70 177
1998	61 399	1 728	2 046	5 266	70 439
1999	62 577	1 778	1 755	5 070	71 180
2000	63 777	1 843	1 833	5 300	72 753
2001	63 313	1 810	1 678	5 905	72 706
2002	65 119	1 894	1 695	5 295	74 002
2003	67 038	1 945	1 696	5 053	75 732
2004	69 556	2 089	1 814	5 286	78 744
2005	70 322	2 245	2 032	5 623	80 222
2006	70 461	2 317	1 983	6 242	81 003
2007	72 001	2 391	2 073	6 801	83 267
Forecasts					
2008	73 093	2 516	2 137	7 003	84 750
2009	74 926	2 620	2 200	7 223	86 970
2010	76 384	2 715	2 269	7 444	88 812
2011	77 627	2 798	2 316	7 659	90 399
2012	78 760	2 853	2 325	7 833	91 771
2013	79 885	2 909	2 338	7 992	93 124
2014	81 025	2 977	2 357	8 141	94 500
2015	82 198	3 041	2 374	8 276	95 888
2016	83 303	3 099	2 389	8 387	97 179
2017	84 420	3 153	2 398	8 494	98 465
2018	85 504	3 205	2 403	8 599	99 710
2019	86 716	3 259	2 410	8 703	101 088
2020	87 819	3 316	2 419	8 809	102 362

Notes: Emission estimates for carbon dioxide relate to full fuel combustion of carbon, with typically 1 per cent allowance for uncombusted material (i.e. includes carbon actually released from the engine as carbon monoxide and volatile organic compounds, which eventually oxidises to CO_2, but excludes 1 per cent of fuel carbon that is assumed to be converted into solid products such as soot).

Emission estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways). Emissions exclude CO_2 released from the combustion of biofuels.

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation. 'Maritime' includes emissions from small pleasure craft and ferries, and from fuel use by international vessels undertaking a domestic shipping task. Emissions due to military transport are excluded.

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 1.4 Base case projections of methane emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams CH_4)		
1990	22.62	0.15	2.30	0.29	25.36
1991	22.49	0.15	2.35	0.25	25.23
1992	22.97	0.14	2.48	0.24	25.83
1993	23.66	0.14	2.63	0.26	26.69
1994	24.23	0.15	2.77	0.26	27.41
1995	24.97	0.15	2.95	0.27	28.34
1996	25.19	0.14	3.10	0.27	28.71
1997	25.28	0.15	3.22	0.28	28.93
1998	25.27	0.15	3.32	0.28	29.01
1999	25.31	0.15	3.48	0.28	29.22
2000	25.20	0.16	3.65	0.28	29.28
2001	24.25	0.16	3.73	0.28	28.43
2002	24.20	0.16	3.92	0.26	28.55
2003	24.28	0.17	4.14	0.25	28.84
2004	24.51	0.17	4.43	0.25	29.37
2005	23.78	0.18	4.58	0.26	28.79
2006	22.89	0.18	3.99	0.26	27.33
2007	22.55	0.19	4.05	0.27	27.05
Forecasts					
2008	22.20	0.20	4.10	0.28	26.77
2009	22.29	0.20	4.14	0.29	26.93
2010	22.08	0.21	4.19	0.29	26.78
2011	21.70	0.22	4.24	0.30	26.45
2012	21.32	0.22	4.28	0.30	26.13
2013	20.98	0.23	4.32	0.31	25.84
2014	20.71	0.23	4.36	0.31	25.61
2015	20.47	0.24	4.40	0.31	25.42
2016	20.40	0.24	4.44	0.31	25.40
2017	20.22	0.25	4.48	0.32	25.27
2018	20.21	0.25	4.52	0.32	25.30
2019	20.25	0.26	4.56	0.32	25.39
2020	20.21	0.26	4.60	0.32	25.40

Notes: Emission estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways).

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation. 'Maritime' includes emissions from small pleasure craft and ferries, and from all fuel consumption for the coastal shipping task. Emissions due to military transport are excluded.

Sources: BITRE estimates, BTRE (2006a, 2003a, 2003c, 2002a), BTCE (1996a, 1995a).

Table 1.5 Base case projections of nitrous oxide emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams N_2O)		
1990	2.02	0.05	0.08	0.08	2.23
1991	2.29	0.05	0.07	0.10	2.51
1992	2.57	0.05	0.07	0.11	2.79
1993	2.90	0.05	0.06	0.11	3.12
1994	3.24	0.05	0.05	0.12	3.46
1995	3.62	0.05	0.07	0.14	3.88
1996	3.94	0.05	0.07	0.15	4.22
1997	4.20	0.05	0.07	0.17	4.48
1998	4.44	0.05	0.06	0.15	4.70
1999	4.74	0.05	0.05	0.14	4.98
2000	5.02	0.05	0.05	0.15	5.28
2001	5.14	0.05	0.05	0.17	5.41
2002	5.44	0.05	0.05	0.15	5.70
2003	5.70	0.05	0.05	0.14	5.95
2004	5.98	0.05	0.05	0.15	6.24
2005	5.99	0.06	0.06	0.16	6.26
2006	5.93	0.06	0.06	0.18	6.22
2007	6.04	0.06	0.06	0.19	6.35
Forecasts					
2008	6.13	0.06	0.06	0.20	6.45
2009	6.30	0.06	0.06	0.21	6.63
2010	6.41	0.06	0.06	0.21	6.75
2011	6.50	0.06	0.07	0.22	6.84
2012	6.56	0.06	0.07	0.22	6.91
2013	6.61	0.06	0.07	0.23	6.97
2014	6.67	0.07	0.07	0.23	7.04
2015	6.72	0.07	0.07	0.24	7.09
2016	6.75	0.07	0.07	0.24	7.13
2017	6.79	0.07	0.07	0.24	7.17
2018	6.82	0.07	0.07	0.25	7.20
2019	6.87	0.07	0.07	0.25	7.26
2020	6.88	0.07	0.07	0.25	7.28

Notes: Emission estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways).

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation. 'Maritime' includes emissions from small pleasure craft and ferries, and from all fuel consumption for the coastal shipping task. Emissions due to military transport are excluded.

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Chapter 2 Projections by transport mode

Road sector emission projections

Emissions from the Australian road transport sector in 2010 are projected (in BITRE Base Case 2007), to be close to 44 per cent above the level for 1990, reaching around 78.7 million tonnes of direct CO_2 equivalent (allowing for the exclusion from the total of CO_2 emissions released during the combustion of biofuels). By 2020, the projected base case emissions for road transport increase to 65 per cent above 1990 levels (at about 90.3 million tonnes of CO_2 equivalent), under the BAU assumptions.

The BITRE base case projections for the road sector have vehicle kilometres travelled (VKT) growing steadily over the projection period, with estimated total national VKT of 223.2 billion kilometres in 2006–07 projected to increase by over 25 per cent (or close to 1.75 per cent per annum) by 2020, to around 279.4 billion vehicle kilometres. Underlying growth in the total vehicle stock should exhibit a similar growth pattern, with the total number of Australian vehicles on-road rising from around 14.7 million at the end of 2006–07, to a projected 18.1 million vehicles by 2019–20 (see Figure 2.1). Metropolitan VKT is projected to grow at a faster rate than non-urban travel—metropolitan car use is projected to increase by about 22 per cent between 2007 and 2020, and non-metropolitan car use by about 17 per cent.

The projected increase of about 25.2 per cent in national VKT by all vehicles (between 2007 and 2020) is comprised of an increase of about 19.9 per cent in travel by passenger cars (including 4WD passenger vehicles), 47.4 per cent by light commercial vehicles (LCVs), 17.2 per cent by rigid trucks, 43.2 per cent by articulated trucks, 28.6 per cent by commercial buses and 33.4 per cent by on-road motorcycles (see Figure 2.2).

Projected total VKT growth would have been considerably stronger if all vehicle types had their activity levels as closely tied to economic growth as freight vehicles. Commercial vehicle utilisation is projected to grow at a substantially higher rate than that for private vehicle travel, with the freight task likely to continue exhibiting growth rates roughly proportional to GDP growth, at least for the medium-term.

However, growth in personal vehicle travel (i.e. per capita kilometres travelled in passenger cars) has slowed markedly over time, especially after the early 1990s. It thus appears that Australians are already approaching a level of travel each day that uses up as much of their average daily time budget as they are willing to commit. Any further car travel, beyond such an asymptotic saturation level in per capita kilometres, would not be an attractive option to most people, even if average incomes continued rising.

The BITRE FuelCar submodule of CARMOD (BITRE's model of car fleet dynamics) uses a structural approach whereby passenger vehicle travel per person has been modelled as a saturating curve, relative to real Australian income per person (using per capita Gross Domestic Product, in constant dollar terms). A logistic curve (calibrated using more than 50 years of travel estimates) gives a reasonably close fit (see Figure 2.3).

It could be argued that eventually a similar effect should become evident for freight vehicle use and if the projections were over a longer time period, the models would probably need to allow for eventual saturation effects in per capita goods movement as well as in per capita daily car travel. However, this should not be an issue for the current projections to 2020. Since there is not yet any evidence of a growth slowdown in Australian per capita road freight (as is already apparent for car VKT per person), and there appears to be significant scope for further growth (e.g. tonnes of non-urban freight per person in the USA are considerably higher than current Australian levels), the BITRE assessment is that growth in Australian aggregate freight tonne kilometres (TKM) is unlikely to decouple from income (GDP) growth within the projection period.

It is worth noting, however, that there are clear signs of a decoupling of aggregate economic growth (in GDP terms) and freight transport demand having already occurred in the United Kingdom. The UK Commission for Integrated Transport (2007) has presented results showing a gradual decline there, in average tonne kilometres per unit of GDP, over recent years. This is likely due to changes in the structure of the UK economy, with shifts over time, away from traditional primary industries, and towards service-based and information technology-related sectors (in which freight transportation tends to play a lesser role). Since the economic structure of many countries show similar trends (i.e. of movements towards higher value, less freight intensive production), this UK decoupling experience could be replicated more widely in the coming years.

Besides economic growth, the other main influence on the aggregate demand for freight transport is the real freight rate. Real road freight rates in Australia have fallen dramatically since 1965, mainly driven by the progressive introduction of larger articulated vehicles, but also by technological change which has made possible lighter vehicles and improved terminal efficiencies. Real freight rates fell around 45 per cent from 1965 to 1990, and then a further 3 per cent in the 1990s. Recent high fuel prices have, however, caused some increases in average freight rates.

The current base case modelling assumes that continuing innovation (technological and logistical) will deliver intrinsic efficiency improvements such that, under average historical circumstances, around 0.5 per cent per annum reductions in real road freight rates would have been possible over the projection period, but that pressures on operating costs from continuing relatively high fuel prices and other factors (such as possible overheads in the future from complying with stricter environmental or vehicle design standards) will approximately halve this rate of reduction over the next decade or so. These factors, combined with the probable eventual saturation of some of the major efficiency trends (e.g. penetration of B-doubles into permitted markets/areas), are assumed to result in the longer-term trend being essentially constant real rates.

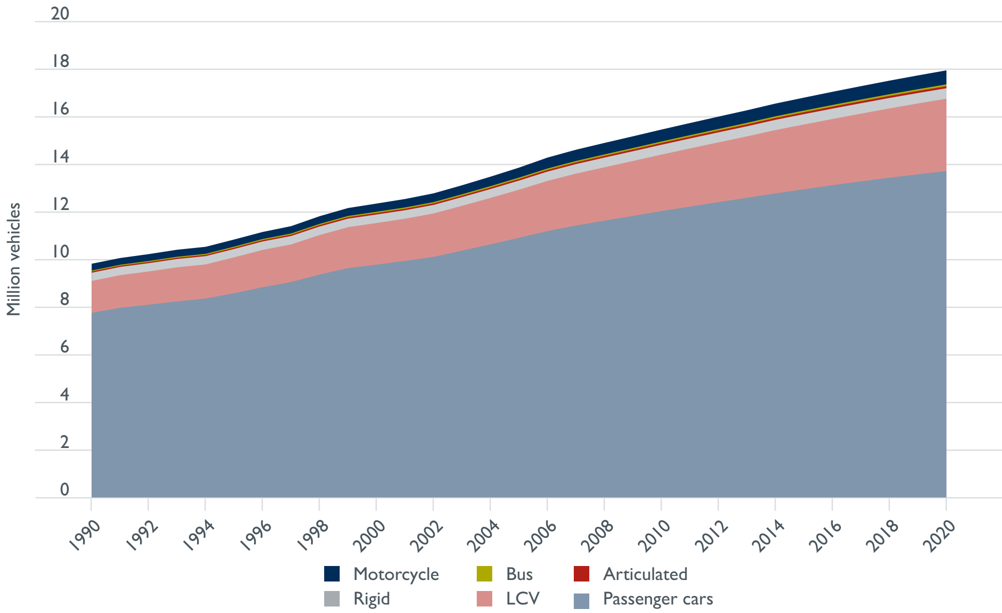
The BITRE truck use forecasts to 2020 are largely based on projected growth in GDP (where the income elasticity has been derived as between 0.96 and 1.02, depending on the freight category), along with slight overall reductions in freight rates (with a real freight rate elasticity between –0.7 and –0.8). The road freight model (which incorporates separate parameter estimates for each capital city and for non-metropolitan freight movement) gives an expected growth in aggregate road TKM averaging roughly 3.6 per cent per annum between 2007 and 2020.

The BITRE base case incorporates the effects of:

- future economic growth and increasing national population levels (and a consequent increase in demand for travel)
- an increasing proportion of the Australian population living in urban areas
- increasing urban traffic congestion levels
- some deterioration in the average emissions performance as vehicles age and/or are not adequately maintained (meaning that the fleet does not improve as rapidly, in terms of its average grams of CO_2 equivalent emitted per kilometre, as would be expected purely from the results of testing new vehicles)
- an increasing proportion of total travel accounted for by the heavier, commercial component of the vehicle fleet (since forecast rates of growth are stronger for total truck VKT than for car VKT).

Total fuel consumption by the road sector is thus projected to rise substantially over the projection period (at close to 1.6 per cent per annum between 2007 and 2020), despite the saturating trend in per capita car travel and an expected continuation of improvements in the (rated) fuel efficiency of new vehicles (see Tables 2.1 and 2.2 for projected light vehicle fuel intensity trends and Figure 2.4 for projected fuel consumption by the various vehicle types).

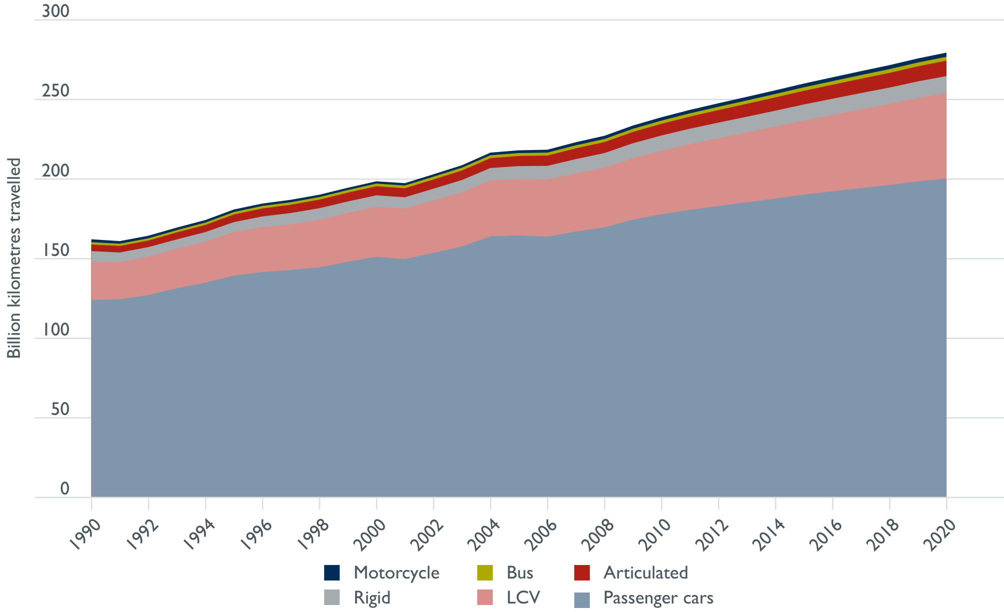
Figure 2.1 Base case projected growth in road vehicle stock for Australia, 1990–2020



Notes: 'Passenger cars' include 4WD passenger vehicles, commonly called 'All Terrain Wagons' (ATWs).
'Bus' refers to all commercial passenger vehicles with 10 or more seats (including long-distance coaches).
'Articulated' refers to all articulated trucks (including B-doubles and road trains).
'Rigid' includes all heavy vehicles that are not articulated trucks or buses.
'LCV' refers to light commercial vehicle.
'Motorcycle' refers to those registered for on-road use.

Sources: ABS (2006a, 2006b and earlier), BTRE (2002a, 2003c, 2006a, 2007a) and BITRE estimates.

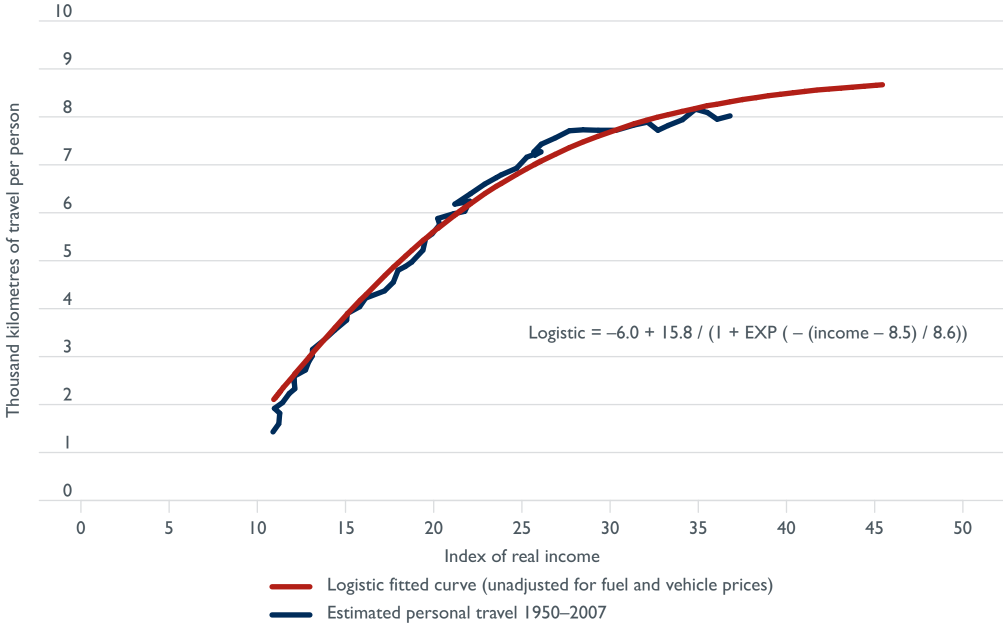
Figure 2.2 Base case projected growth in road vehicle travel for Australia, 1990–2020



Notes: 'Passenger cars' include 4WD passenger vehicles, commonly called 'All Terrain Wagons' (ATWs).
'Bus' refers to all commercial passenger vehicles with 10 or more seats (including long-distance coaches).
'Articulated' refers to all articulated trucks (including B-doubles and road trains).
'Rigid' includes all heavy vehicles that are not articulated trucks or buses.
'LCV' refers to light commercial vehicle.
'Motorcycle' refers to those registered for on-road use.

Sources: ABS (2006a and earlier), BTRE (2002a, 2003c, 2006a, 2007a) and BITRE estimates.

Figure 2.3 Relationship of per capita car travel to per capita income



Sources: ABS (2006a and earlier, 2006c, 2006d), BTRE (2002a, 2006a, 2007a), Cosgrove and Gargett (1992, 2007), Cosgrove and Mitchell (2001) and BITRE estimates.

Tables 2.1 and 2.2 give the forecast average fuel intensity (rated fuel consumption, litres per 100km) of new light motor vehicles (i.e. all vehicles under 3.5 tonnes gross vehicle mass), where allowance has been made for the fuel efficiency targets currently proposed by motor vehicle manufacturers, as part of the Environmental Strategy for the Motor Vehicle Industry (ESMVI).

For the BITRE base case, the National Average Fuel Consumption (NAFC) targets are assumed to accelerate trend improvement in the average fuel efficiency of new light vehicle sales; such that in Base Case 2007, new passenger cars are projected to have, on average, an 11.5 per cent lower rated fuel intensity in 2010 relative to 2003 (and get to 20.1 per cent lower by 2020). New LCV sales are projected to have around 7.5 per cent lower rated fuel intensity in 2010 relative to average 2003 levels (and reach 15 per cent lower by 2020).

Table 2.1 Base case projections of new passenger car fuel intensity, 1990–2020

Year	*Rated fuel consumption for 'standard' passenger cars[a]* (L/100km gasoline equivalent)	*Rated fuel consumption for 4WD passenger vehicles (ATWs)[a]* (L/100km gasoline equivalent)	*Percentage of new passenger vehicle sales accounted for by ATWs[b]* (per cent)	*Percentage of new passenger vehicle sales accounted for by hybrids[c]* (per cent)	*Weighted average new passenger car fuel intensity[a]* (L/100km gasoline equivalent)
1990	8.65	12.98	8.1	0.0	9.00
1991	8.42	12.82	8.4	0.0	8.79
1992	8.41	12.89	8.9	0.0	8.81
1993	8.45	12.36	10.0	0.0	8.85
1994	8.51	12.12	11.1	0.0	8.90
1995	8.44	12.26	8.5	0.0	8.77
1996	8.33	12.35	8.7	0.0	8.68
1997	8.32	12.25	10.4	0.0	8.73
1998	8.14	11.69	13.2	0.0	8.61
1999	8.11	11.59	14.9	0.0	8.63
2000	8.11	11.24	16.3	0.0	8.62
2001	7.99	11.41	17.1	0.0	8.58
2002	7.94	11.28	19.4	0.0	8.59
2003	7.85	10.92	20.4	0.1	8.47
2004	7.77	10.70	21.2	0.1	8.39
2005	7.72	10.43	23.3	0.2	8.34
2006	7.53	10.20	22.3	0.3	8.12
2007	7.45	10.10	22.4	0.5	8.03
Forecasts					
2008	7.34	9.90	22.5	0.7	7.90
2009	7.23	9.71	22.7	0.8	7.77
2010	6.98	9.67	23.0	1.0	7.57
2011	6.91	9.58	23.2	1.3	7.50
2012	6.85	9.49	23.4	1.6	7.43
2013	6.78	9.40	23.6	2.0	7.35
2014	6.72	9.31	23.8	2.6	7.28
2015	6.65	9.22	24.0	3.2	7.20
2016	6.59	9.13	24.2	4.0	7.12
2017	6.52	9.04	24.4	5.0	7.04
2018	6.46	8.95	24.6	6.2	6.95
2019	6.39	8.86	24.8	7.7	6.86
2020	6.33	8.77	25.0	9.7	6.77

a. NAFC—'National Average Fuel Consumption'—values refer to dynamometer cycle testing (as opposed to actual on-road fuel intensity). Rated fuel consumption is given in litres of fuel, in gasoline equivalent energy terms, used per 100 kilometres travelled (L/100km)—averaged over the test's length and over the possible fuel types (which include automotive gasoline, diesel, LPG, natural gas and ethanol blends; i.e. assuming that electric vehicles, including plug-in hybrids, and hydrogen fuel-cell vehicles both play relatively negligible roles in the Australian passenger vehicle market over the 2020 timeframe).

b. ATWs are 'All Terrain Wagons' (4WD passenger vehicles).

c. Hybrids are hybrid petrol-electric passenger vehicles.

Sources: ABS (2006a, 2006b), BTRE (2007a, 2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 2.2 Base case projections of new light commercial vehicle (LCV) fuel intensity, 1990–2020

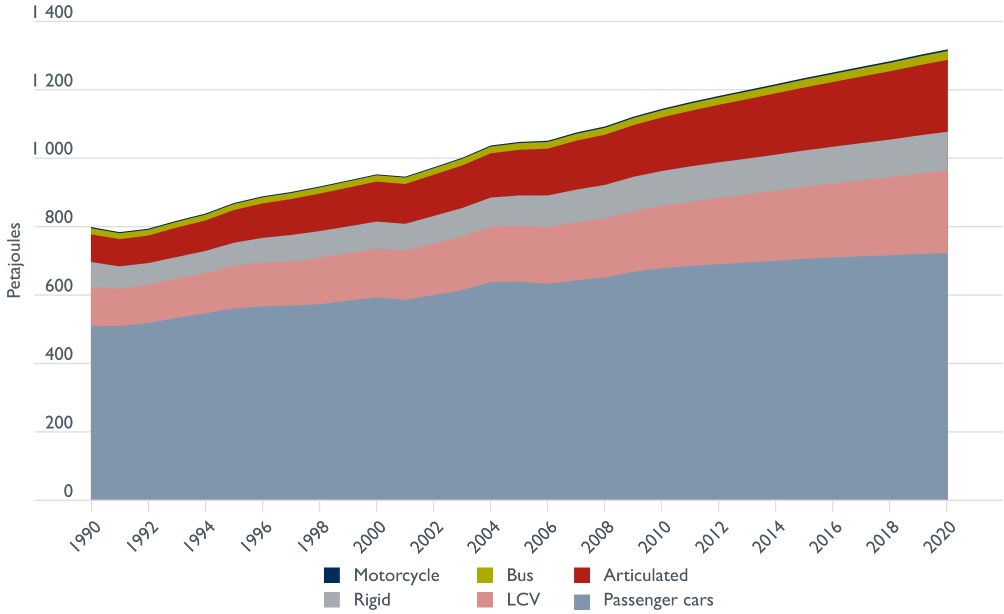
Financial year	*Rated fuel consumption for LCVs*[a] *(L/100km gasoline equivalent)*	*Assumed percentage of new LCV sales due to 4WD vehicles*[b] *(per cent)*
1990	9.72	27.0
1991	9.72	27.0
1992	9.91	31.2
1993	10.58	39.5
1994	10.40	35.0
1995	10.35	33.8
1996	10.34	33.6
1997	10.41	35.2
1998	10.48	37.0
1999	10.52	38.0
2000	10.62	36.0
2001	10.86	34.0
2002	10.76	35.0
2003	10.62	35.0
2004	10.51	36.0
2005	10.41	37.0
2006	10.35	39.0
2007	10.22	39.2
Forecasts		
2008	10.09	39.4
2009	9.95	39.6
2010	9.82	39.8
2011	9.74	40.0
2012	9.66	40.2
2013	9.58	40.4
2014	9.51	40.6
2015	9.43	40.8
2016	9.35	41.0
2017	9.27	41.2
2018	9.19	41.4
2019	9.11	41.6
2020	9.03	41.8

a. NAFC—'National Average Fuel Consumption', and refers to dynamometer cycle testing (as opposed to actual on-road fuel intensity).

b. 4WD vehicles include all sales of 'Pickup and Cab Chassis 4x4s'.

Sources: ABS (2006a, 2006b), BTRE (200a7, 2006a, 2003a, 2002a) and BITRE estimates.

Figure 2.4 Base case projected growth in energy consumption by road vehicles for Australia, 1990–2020

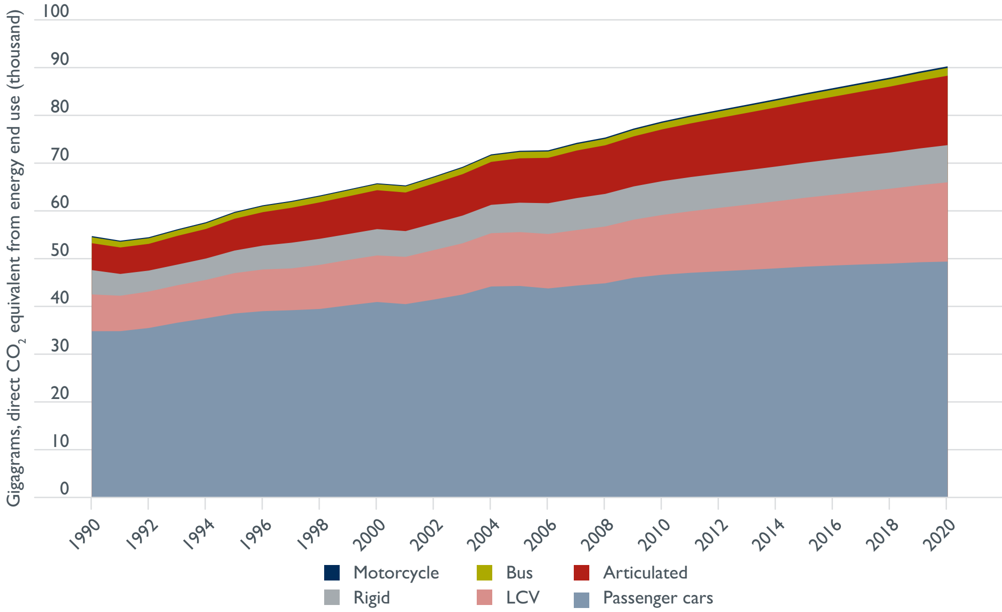


Notes: Cars include 4WD passenger vehicles ('All Terrain Wagons'—ATWs). LCVs refer to light commercial vehicles.
'Rigid' refers to all non-articulated truck types.
Petajoules (PJ) = 10^{15} Joules.

Sources: ABARE (2006, 2007a), ABS (2006a and earlier), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), DITR (2004, 2007a) and BITRE estimates.

The resulting emissions trend for road vehicles is plotted in Figure 2.5 (the year-by-year values were listed in Table 1.1).

Figure 2.5 Base case projected growth in greenhouse gas emissions by road vehicles for Australia, 1990–2020



Notes: Emission estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing). Emissions exclude CO_2 released from the combustion of biofuels.

Cars include 4WD passenger vehicles ('All Terrain Wagons'—ATWs). LCVs refers to light commercial vehicles.

'Rigid' refers to all non-articulated truck types.

Sources: ABARE (2007a), ABS (2006a and earlier), BTE (1999a), BTRE (2002a, 2003a, 2006a, 2007a), DITR (2007a, 2004) and BITRE estimates.

Rail sector emission projections

End use emissions (i.e. excluding power generation for electric rail) from the Australian rail transport sector in 2010 are projected (in the current BITRE base case), to be around 58 per cent above the level for 1990, reaching 2.74 million tonnes of CO_2 equivalent. By 2020, the projected base case emissions (end use) for rail transport increase to about 79 per cent above 1990 levels (at 3.34 million tonnes of CO_2 equivalent).

BITRE's methodology uses a combination of mathematical and econometric models to project rail passenger and freight tasks and the resulting energy consumption. Rail uses both petroleum-based fuels (primarily diesel) and electricity, so total energy consumption (expressed in petajoules of energy end use and modelled as the product of the railway tasks and of respective energy intensity levels) has to be disaggregated carefully when calculating emissions. BITRE's models forecast total rail emissions, both from non-electric rail (direct fuel combustion) and electric rail (emissions due to the required electric power generation). However, since AGO/DCC inventory processes only allocate *non-electric* rail emissions to the *transport* sector (electricity used by railways being accounted for in the *stationary energy* sector), most tables in this report do not include electric rail emissions (though they are included in some sections of the report for the sake of completeness).

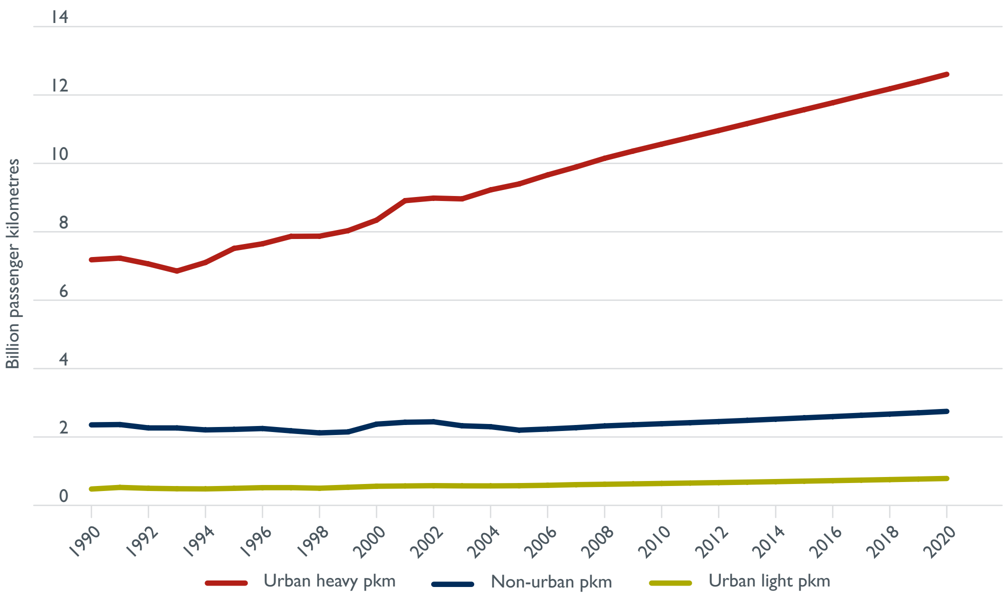
The railway passenger and freight tasks each have three distinct subsectors. The passenger task is comprised of urban light rail, urban heavy rail and non-urban heavy rail. The freight task is comprised of bulk freight and non-bulk freight carried by hire and reward rail operators; and bulk freight carried by ancillary freight operators—generally on privately owned rail lines. The major commodity tonnage carried by such private railway systems is currently iron ore.

Passenger numbers and freight tonnages are modelled and then multiplied by average distances travelled to obtain task levels in passenger kilometres (PKM) and tonne kilometres.

Rail task projections in Base Case 2007 are substantially higher than those in *Base Case 2005* (BTRE 2006a), primarily due to strong export growth driving continued growth in the movement of bulk raw materials, and to a combination of improved infrastructure, high petrol prices and increasing traffic congestion leading to relatively strong patronage growth on public transport.

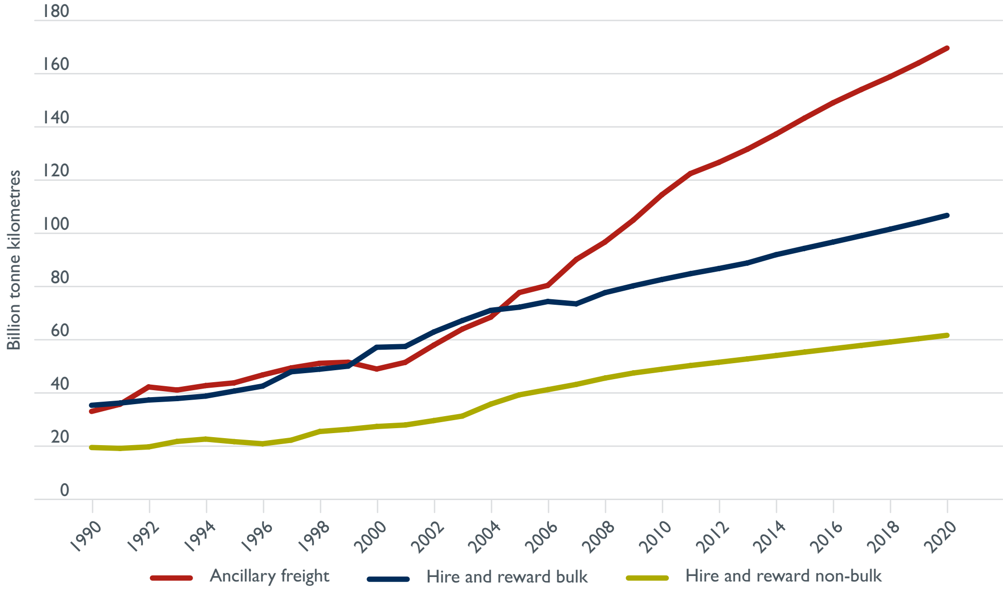
Rail passenger task projections are shown in Figure 2.6, while the freight task projections are shown in Figure 2.7. Figure 2.8, and Table 2.3, show total passenger and freight rail emission levels, split between electric and non-electric railways. A range of time series values dealing with the base case projections for rail transport are provided in the Appendix.

Figure 2.6 Base case projections of rail passenger tasks for Australia, 1990–2020



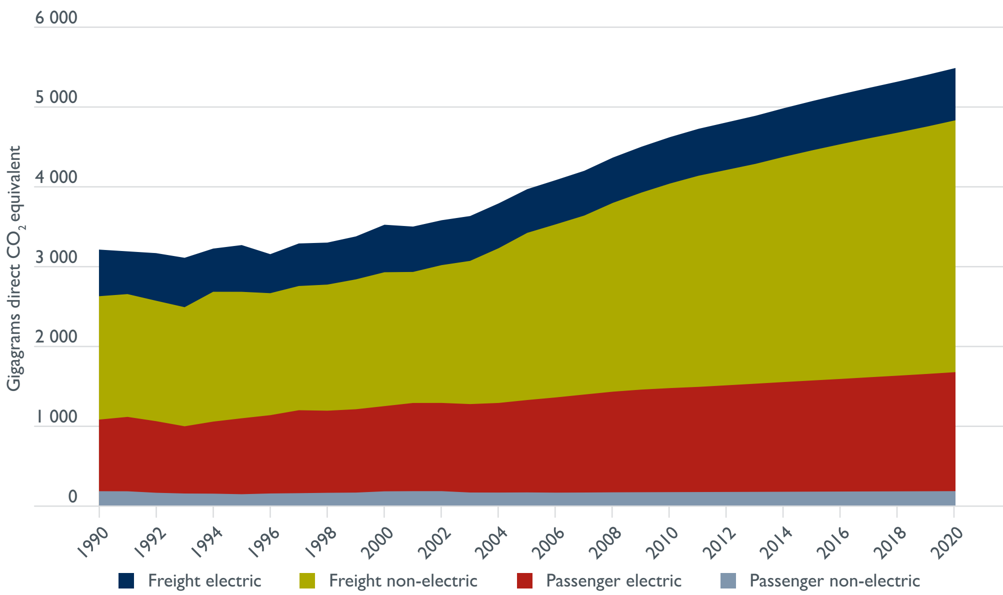
Sources: ACG (2007), BTCE (1996a), BTRE (2002a, 2003b, 2006a, 2007a) and BITRE estimates.

Figure 2.7 Base case projections of rail freight tasks for Australian railways, 1990–2020



Sources: ABARE (2007b), ACG (2007), BTCE (1996a), BTRE (2002a, 2003b, 2006a) and BITRE estimates.

Figure 2.8 Base case projections of total rail emissions (including both electric and non-electric railways) for Australia, 1990–2020



Note: Estimates here include emissions from power generation for electric railways.

Sources: ABARE (2007a, 2007b), ACG (2007), BTCE (1996a), BTRE (2002a, 2003b, 2006a) and BITRE estimates.

Table 2.3 Base case projections of direct greenhouse gas emissions for Australian railways (electric and non-electric), 1990–2020

Financial year	*Passenger*		*Freight*		*Total*		
	Non-electric	*Electric*	*Non-electric*	*Electric*	*Non-electric*	*Electric*	*All*
	(gigagrams of CO_2 equivalent)						
1990	186.9	897.0	1 545.9	584.0	1 732.9	1 481.0	3 213.9
1991	186.0	931.8	1 538.5	535.5	1 724.5	1 467.3	3 191.8
1992	167.5	896.8	1 508.9	596.3	1 676.4	1 493.1	3 169.5
1993	158.2	842.1	1 492.0	618.9	1 650.2	1 461.0	3 111.1
1994	156.4	902.6	1 626.6	541.0	1 782.9	1 443.6	3 226.5
1995	149.3	951.2	1 584.7	585.3	1 733.9	1 536.5	3 270.4
1996	158.6	980.8	1 528.4	488.8	1 687.0	1 469.7	3 156.6
1997	162.3	1 039.2	1 556.3	532.9	1 718.6	1 572.1	3 290.7
1998	167.0	1 028.6	1 579.8	526.1	1 746.8	1 554.7	3 301.5
1999	169.8	1 044.0	1 627.2	537.9	1 797.0	1 581.9	3 378.9
2000	185.4	1 067.5	1 677.4	595.0	1 862.8	1 662.5	3 525.3
2001	187.5	1 104.7	1 641.8	568.2	1 829.3	1 672.9	3 502.3
2002	187.7	1 105.1	1 726.6	562.3	1 914.3	1 667.4	3 581.7
2003	170.6	1 107.7	1 794.2	561.8	1 964.8	1 669.5	3 634.4
2004	170.0	1 122.6	1 939.1	561.3	2 109.1	1 683.9	3 793.0
2005	171.9	1 157.5	2 094.2	547.5	2 266.1	1 705.0	3 971.1
2006	169.0	1 192.7	2 168.9	554.1	2 337.9	1 746.7	4 084.7
2007	170.5	1 227.6	2 242.5	560.7	2 413.0	1 788.3	4 201.3
Forecasts							
2008	173.0	1 260.8	2 365.7	567.4	2 538.7	1 828.2	4 366.8
2009	174.3	1 285.7	2 468.2	574.3	2 642.5	1 860.0	4 502.5
2010	175.5	1 303.3	2 563.0	581.2	2 738.5	1 884.4	4 622.9
2011	176.6	1 317.5	2 645.1	588.1	2 821.7	1 905.6	4 727.3
2012	177.7	1 336.2	2 699.8	595.2	2 877.5	1 931.3	4 808.8
2013	178.9	1 355.1	2 754.4	602.3	2 933.3	1 957.4	4 890.7
2014	180.3	1 374.4	2 822.3	609.6	3 002.6	1 984.0	4 986.6
2015	181.7	1 392.9	2 884.5	616.9	3 066.2	2 009.8	5 076.0
2016	182.9	1 411.0	2 942.3	624.3	3 125.3	2 035.3	5 160.5
2017	184.2	1 430.6	2 995.4	631.8	3 179.6	2 062.4	5 242.0
2018	185.3	1 449.5	3 046.2	639.4	3 231.5	2 088.9	5 320.3
2019	186.5	1 469.4	3 099.3	647.0	3 285.8	2 116.5	5 402.3
2020	187.9	1 490.6	3 155.6	654.8	3 343.4	2 145.5	5 488.9

Notes: Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Estimates here include emissions from power generation for electric railways (otherwise energy end use emissions, i.e. do not include other upstream fuel supply and processing emissions).

Sources: ABARE (2007a), ACG (2007), BTCE (1996a, 1995a), BTRE (2006a, 2003b, 2002a) and BITRE estimates.

Maritime sector emission projections

Emissions from the Australian maritime sector in 2010 are projected (in the current BITRE base case), to be approximately equal to the level for 1990, at about 2.4 million tonnes of direct CO_2 equivalent. By 2020, the projected marine transport emissions increase moderately from the 2010 level, to be about 6.3 per cent above 1990 levels (at about 2.54 million tonnes of CO_2 equivalent).

The calculation of maritime emissions is complicated by the wide variety of activities within the sector, and their varied fuel sources. For example, a mix of automotive distillate, industrial diesel fuel, heavy fuel oil, coal, natural gas and automotive gasoline is consumed within the sector; used by domestic shipping, international shipping, coastal ferries, inland ferries, pleasure craft, cruise ships, fishing boats and military craft. Fuel is bought both locally (primarily from marine bunkers, but also from standard automotive sources for smaller craft) and overseas (especially for international shipping).

The dominant activity for shipping is the long-distance carriage of bulk goods and estimating emissions for the maritime sector essentially relies on projecting bulk commodity movements. BITRE projections of shipping freight tasks are plotted in Figure 2.9 for coastal shipping and Figure 2.10 for international shipping (all vessels servicing Australian trade).

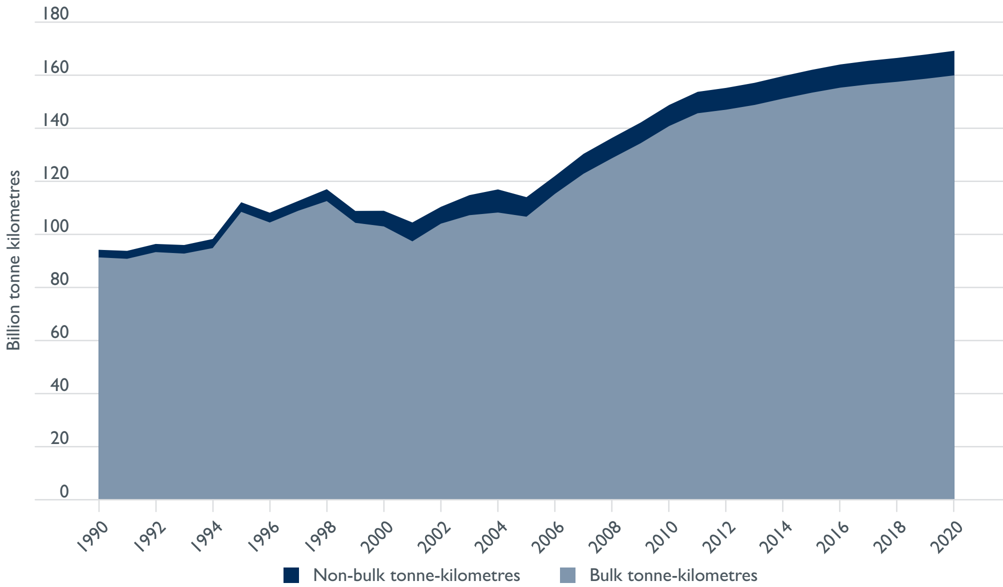
Since fuel is generally more expensive in Australia than in some other countries, only a small proportion of the fuel used in international shipping services, (to and from Australia, is uplifted in Australia (typically about 6 to 9 per cent). The approach adopted by BITRE in modelling the uplift of bunker fuel in Australia for international shipping involves two parts. Firstly, a model of the total international shipping task servicing Australian trade (and consequent total fuel use) comprises the basic model. Secondly, once total fuel use has been modelled, the fraction of this total that is uplifted in Australia is estimated.

Table 2.4 gives the estimated fuel consumption for the international shipping fleet (visiting Australia), along with fuel use by the domestic (civil) sector. Australian maritime emissions (CO_2 equivalent) are given in Table 2.5, where international shipping figures here relate to the amount of fuel uplifted in Australia.

The BITRE emission estimates follow the NGGI guidelines and exclude fuel used by military vessels. The emission totals given in Table 2.5 thus include the output from all civil domestic shipping activity (including any fuel use by international vessels undertaking domestic freight movement), ferry traffic, and the use of small pleasure craft, with a rough allowance made to exclude any fuel use by fishing vessels that might appear in the marine bunker sales data. However, due to fuel accounting problems brought on by the abovementioned diverse operations within the sector, the domestic marine sector emission estimates are quite approximate, and the current background data do not appear to be available in enough detail to allow an exact year-by-year quantification of all the required inclusions (e.g. from automotive fuel sales for small craft) and exclusions (e.g. for international bunker fuel use, military vessel fuel use in domestic waters, and fishing boat fuel use).

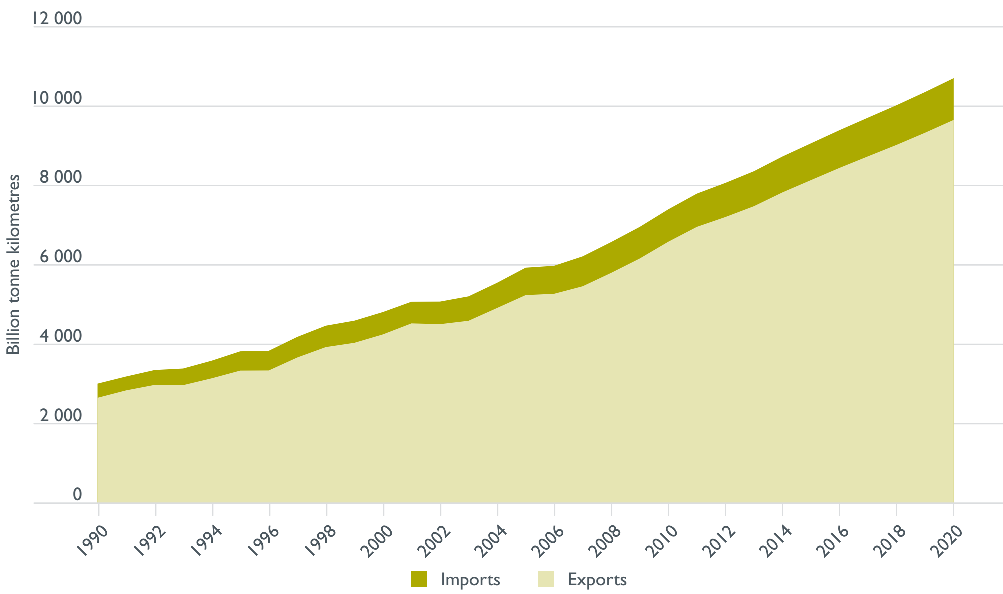
A range of time series values (dealing with the maritime base case projections) are provided in the Appendix.

Figure 2.9 Base case projections of freight tasks performed by Australian coastal shipping, 1990–2020



Sources: ACG (2007), BTCE (1995a), BTRE (2002a, 2003b, 2006a, 2007b) and BITRE estimates.

Figure 2.10 Base case projections of freight tasks performed by international shipping into and out of Australia, 1990–2020



Sources: ABARE (2007b), ACG (2007), BTCE (1996a, 1995a), BTRE (2002a, 2006a, 2007b) and BITRE estimates.

Table 2.4 Base case projections of fuel consumption by Australian civil maritime sector, 1990–2020

Financial year	*Domestic*			*International*	
	Coastal shipping	*Other marine*	*Total*	*Total for all shipping servicing Australian trade*	*Bunker fuel uplifted in Australia*
			(PJ energy end use)		
1990	25.39	6.30	31.70	316.4	27.1
1991	20.95	6.51	27.46	345.7	24.2
1992	21.39	6.86	28.25	366.0	23.2
1993	18.29	7.31	25.60	373.6	23.2
1994	16.11	7.73	23.84	397.9	26.0
1995	22.58	8.16	30.74	434.2	34.8
1996	23.92	8.56	32.48	415.5	34.9
1997	23.39	8.89	32.29	436.5	31.7
1998	18.94	9.22	28.16	417.2	27.3
1999	14.45	9.67	24.12	416.9	30.8
2000	15.02	10.13	25.14	424.0	33.9
2001	12.88	10.34	23.22	420.0	31.7
2002	12.66	10.85	23.51	384.3	34.7
2003	12.09	11.46	23.56	373.1	34.6
2004	12.88	12.24	25.12	386.2	35.5
2005	15.22	12.62	27.84	410.1	37.7
2006	16.21	11.04	27.25	405.9	36.5
2007	17.25	11.18	28.43	408.7	36.8
Forecasts					
2008	17.97	11.31	29.29	421.4	37.9
2009	18.69	11.44	30.13	434.0	39.1
2010	19.47	11.57	31.03	449.4	40.4
2011	19.97	11.69	31.66	461.0	41.5
2012	19.99	11.81	31.80	464.5	41.8
2013	20.06	11.92	31.98	468.9	42.2
2014	20.21	12.03	32.24	476.9	42.9
2015	20.33	12.15	32.48	482.2	43.4
2016	20.43	12.26	32.69	486.9	43.8
2017	20.44	12.37	32.82	490.2	44.1
2018	20.41	12.48	32.90	493.0	44.4
2019	20.41	12.59	33.01	496.2	44.7
2020	20.43	12.70	33.13	499.7	45.0

Notes: 'Other marine' is comprised of ferries (interstate and urban) and pleasure craft.
'Coastal shipping' includes some fuel used by international vessels undertaking a domestic shipping task.
Petajoules (PJ) = 10^{15} Joules.

Sources: ABARE (2007a), ACG (2007), BTCE (1996a, 1995a), BTRE (2006a, 2003b, 2002a) and BITRE estimates.

Table 2.5 Base case projections of direct greenhouse gas emissions by Australian civil maritime sector, 1990–2020

Financial year	*Domestic*			*International*
	Coastal shipping	*Other marine*	*Total*	*For fuel uplifted in Australia*
		(gigagrams of CO_2 equivalent)		
1990	1 915	472	2 387	1 975
1991	1 596	487	2 083	1 772
1992	1 629	513	2 142	1 699
1993	1 404	547	1 951	1 695
1994	1 239	578	1 817	1 899
1995	1 710	611	2 321	2 542
1996	1 805	640	2 445	2 555
1997	1 770	666	2 436	2 317
1998	1 445	690	2 135	2 002
1999	1 119	724	1 843	2 264
2000	1 168	758	1 926	2 495
2001	997	775	1 772	2 327
2002	979	813	1 792	2 545
2003	939	859	1 798	2 535
2004	1 006	917	1 923	2 602
2005	1 200	945	2 146	2 761
2006	1 258	827	2 085	2 679
2007	1 339	837	2 176	2 698
Forecasts				
2008	1 395	847	2 242	2 782
2009	1 450	857	2 307	2 866
2010	1 511	866	2 377	2 968
2011	1 550	875	2 425	3 044
2012	1 551	884	2 435	3 067
2013	1 557	892	2 449	3 096
2014	1 568	901	2 470	3 150
2015	1 578	910	2 488	3 184
2016	1 585	918	2 504	3 215
2017	1 586	927	2 513	3 238
2018	1 584	935	2 519	3 256
2019	1 584	943	2 527	3 277
2020	1 586	951	2 537	3 301

Notes: 'Other marine' is comprised of ferries and pleasure craft.
'Coastal shipping' includes fuel used by international vessels undertaking a domestic shipping task.
Emissions are from energy end use.

Sources: ACG (2007), BTCE (1996a, 1995a), BTRE (2006a, 2003b, 2002a) and BITRE estimates.

Aviation sector emission projections

Emissions from the Australian civil aviation sector in 2010 are projected (in the current BITRE base case), to be around 165 per cent above the level for 1990, at around 7.5 million tonnes of direct CO_2 equivalent. By 2020, the projected base case emissions for air transport increase to 214 per cent above 1990 levels (at about 8.9 million tonnes of direct CO_2 equivalent). Note that estimates of only direct CO_2 equivalent emissions tend to considerably underestimate the actual radiative forcing potential of aircraft emissions, since the indirect warming effects—such as those due to high altitude ozone generation, from nitrogen oxide emissions, and to contrail formation—are highly significant for the aviation sector (see Chapter 5 for further discussion of this issue).

BITRE has separate models for the various domestic and international air transport tasks. The domestic aviation industry is essentially split into two groups, depending on the type of fuel used. Aviation gasoline (avgas) is used primarily by the general aviation market and aviation turbine fuel (avtur) is used primarily by scheduled airline services. The general aviation market (which includes charter services, private and training flights, and aerial agricultural work) is relatively small compared to the domestic airline market, accounting for less than 5 per cent of domestic aviation fuel use. Also, avgas consumption has typically changed little over the past 25 years. For many years, international aviation has essentially only used avtur. Approximately 40 per cent of total aviation turbine fuel consumed by international air travel to and from Australia is currently uplifted in Australia.

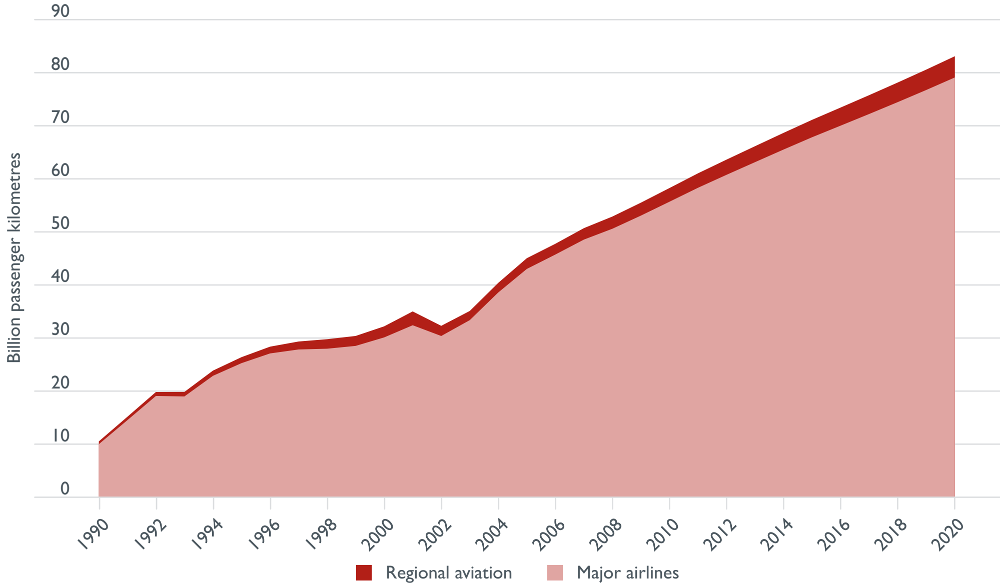
Domestic aviation greenhouse gas emission levels are derived from estimates of domestic civil aviation fuel consumption. This includes fuel used on trunk and regional routes. Military use of aviation fuels is estimated separately and excluded from total sales, and thus from the aviation sector emission estimates.

To estimate fuel consumption, models for the passenger task deal with two major segments separately: Australian resident passengers flying on the domestic network and foreign passengers flying on the domestic network (since variables affecting the number of Australian travellers will tend to differ from those affecting numbers of foreign visitors).

BITRE projections of the total domestic airline passenger task are plotted in Figure 2.11—showing the components due to major airline operations and to regional aviation—and given in Table 2.6, as well as seat kilometres available (SKM). The international task indicators are also given in Table 2.6.

Aviation fuel consumption projections are given in Table 2.7, with aviation emissions (direct CO_2 equivalent) given in Table 2.8, where values for international aviation relate to the component of total fuel consumption that is uplifted in Australia.

Figure 2.11 Base case projections of major passenger tasks performed by Australian civil domestic aviation, 1990–2020



Sources: ACG (2007), BTCE (1996a, 1995a), BTRE (2002a, 2003b, 2006a, 2007c) and BITRE estimates.

Table 2.6 Base case projections of Australian civil aviation tasks, major and regional airlines, 1990–2020

Financial year	*Domestic airlines*			*International aviation*	
	Total passengers on domestic network (million passenger trips)	*Total passenger kilometres on domestic network (million PKM)*	*Total domestic seat kilometres available (million SKM)*	*Estimated total international passengers (thousand passenger trips)*	*Estimated total international seat kilometres available (billion SKM)*
1990	12.31	10 524	14 847	8 476	115.8
1991	16.95	15 160	21 748	8 694	123.1
1992	21.01	19 829	25 703	9 370	129.8
1993	21.48	19 848	26 294	10 171	141.4
1994	24.79	23 862	32 154	10 910	146.2
1995	27.00	26 394	36 685	11 943	162.3
1996	28.61	28 373	39 671	13 124	177.1
1997	29.04	29 344	41 423	14 168	187.8
1998	29.36	29 781	41 077	14 558	197.9
1999	29.73	30 390	41 276	15 004	197.1
2000	31.37	32 204	42 670	15 930	211.5
2001	34.11	35 015	46 709	17 204	219.3
2002	30.51	32 300	42 266	16 389	200.8
2003	32.10	35 104	45 535	15 982	200.8
2004	36.42	40 404	51 745	17 885	225.5
2005	40.43	45 047	58 303	20 310	262.3
2006	42.47	47 762	61 787	21 097	266.1
2007	44.81	50 709	64 667	22 004	271.7
Forecasts					
2008	46.51	52 898	67 390	23 055	284.2
2009	48.52	55 518	70 657	24 374	299.0
2010	50.62	58 270	74 085	25 815	315.1
2011	52.72	61 043	77 534	27 333	332.0
2012	54.62	63 627	80 654	28 716	347.0
2013	56.45	66 157	83 694	30 140	362.4
2014	58.25	68 671	86 701	31 761	380.0
2015	59.97	71 127	89 623	33 441	398.1
2016	61.56	73 443	92 357	35 148	417.2
2017	63.13	75 777	95 101	36 866	436.3
2018	64.73	78 156	97 891	38 603	455.5
2019	66.34	80 591	100 740	40 363	475.8
2020	68.01	83 106	103 676	42 152	496.4

Note: International refers to total passengers into and out of Australia.

Sources: ACG (2007), BTRE (2002a, 2003b, 2006a, 2007c) and BITRE estimates.

Table 2.7 Base case projections of fuel consumption by Australian civil aviation, 1990–2020

Financial year	*Domestic aviation*			*International aviation*	
	Avtur	*Avgas*	*Total*	*Total for all flights into and out of Australia*	*Avtur uplifted in Australia*
	(Petajoules energy end use)				
1990	36.5	4.30	40.8	150.0	63.0
1991	47.2	3.50	50.7	157.7	65.5
1992	51.7	3.30	55.0	164.2	69.5
1993	54.3	3.50	57.8	177.1	75.4
1994	57.7	3.40	61.1	180.9	77.5
1995	68.6	3.46	72.0	198.1	84.9
1996	75.7	3.36	79.0	212.9	91.5
1997	81.0	3.39	84.4	224.0	93.4
1998	73.1	3.44	76.5	233.2	101.7
1999	70.2	3.50	73.7	227.1	101.6
2000	73.6	3.47	77.0	238.7	102.0
2001	82.5	3.35	85.8	243.5	107.8
2002	73.8	3.20	77.0	222.8	92.2
2003	70.4	3.09	73.4	220.2	92.3
2004	73.8	2.98	76.8	242.3	93.0
2005	78.7	3.00	81.7	275.7	103.7
2006	87.8	2.86	90.7	275.5	113.2
2007	95.9	2.94	98.8	279.5	121.6
Forecasts					
2008	98.7	3.05	101.8	289.9	121.7
2009	101.8	3.14	104.9	301.4	126.6
2010	105.0	3.15	108.2	313.8	131.8
2011	108.1	3.16	111.3	326.4	137.1
2012	110.6	3.17	113.8	337.0	141.5
2013	112.9	3.19	116.1	347.6	146.0
2014	115.1	3.20	118.3	359.9	151.2
2015	117.0	3.21	120.2	372.3	156.4
2016	118.6	3.22	121.8	385.1	161.7
2017	120.2	3.24	123.4	397.5	166.9
2018	121.7	3.25	124.9	409.6	172.0
2019	123.2	3.26	126.4	422.2	177.3
2020	124.7	3.27	128.0	435.4	182.9

Notes: Aviation gasoline (avgas) is used primarily by the general aviation market.
Aviation turbine fuel (avtur) is used primarily by scheduled airlines (jet aircraft).
Petajoules (PJ) = 10^{15} Joules.

Sources: ABARE (2007a), ACG (2007), BTCE (1996a), BTRE (2002a, 2003b, 2006a, 2007c), DITR (2007a) and BITRE estimates.

Table 2.8 Base case projections of direct greenhouse gas emissions by Australian civil aviation, 1990–2020

Financial year	*Domestic aviation*			*International aviation*
	Avtur	*Avgas*	*Total*	*Avtur uplifted in Australia*
		(gigagrams of CO_2 equivalent)		
1990	2 541	292	2 833	4 378
1991	3 279	237	3 517	4 555
1992	3 593	224	3 817	4 833
1993	3 774	237	4 012	5 239
1994	4 015	230	4 245	5 391
1995	4 769	235	5 003	5 903
1996	5 263	228	5 491	6 360
1997	5 633	230	5 863	6 491
1998	5 084	233	5 318	7 070
1999	4 883	237	5 120	7 068
2000	5 117	235	5 352	7 092
2001	5 736	227	5 963	7 497
2002	5 130	217	5 347	6 407
2003	4 893	210	5 103	6 421
2004	5 136	202	5 337	6 468
2005	5 474	204	5 678	7 211
2006	6 109	194	6 303	7 870
2007	6 668	199	6 867	8 453
Forecasts				
2008	6 865	207	7 071	8 465
2009	7 080	213	7 293	8 803
2010	7 303	213	7 517	9 163
2011	7 519	214	7 733	9 533
2012	7 694	215	7 909	9 842
2013	7 854	216	8 070	10 152
2014	8 003	217	8 220	10 511
2015	8 138	218	8 356	10 872
2016	8 250	219	8 468	11 246
2017	8 357	219	8 576	11 608
2018	8 462	220	8 682	11 961
2019	8 566	221	8 787	12 328
2020	8 672	222	8 894	12 714

Note: Emissions are from energy end use.

Sources: ABARE (2007a), ACG (2007), BTCE (1996a), BTRE (2002a, 2003b, 2006a, 2007c), DITR (2007a) and BITRE estimates.

Chapter 3 Scenario differences and model details

The Base Case 2007 results are quite comparable in aggregate with each of the base case projection results provided to AGO over the last decade—e.g. see forecast series published in BTRE (2002a, Report 107), BTCE (1996a, Report 94), BTRE (2003b, Information Sheet 21), the commissioned report BTRE (2006a, *Greenhouse Gas Emissions from Australian Transport: Base Case Projections to 2020*); and also unpublished aggregate estimates derived in August 2006 (see Appendix Table A28)—and are similar in subsectoral composition to those of the three studies directly before this one (i.e. Base Cases 2003, 2005 and 2006). The average divergence between the aggregate trend lines of the current Base Case 2007 and any of these three predecessors is less than 2 per cent over the entire projection period (see Figure ES2).

For the aggregate and major sectoral growth rates in domestic transport, over the current projection period:

- the BTRE 2005 base case had growth in total greenhouse emissions for the transport sector (2007–2020) of 21.2 per cent, slightly less than the updated Base Case 2007 result of 22.5 per cent
- road transport emissions in the 2007 update have slightly faster projected growth over the current forecast period (with 1.52 per cent per annum, 2007–2020, in the new base case) compared with 1.45 per cent per annum in the 2005 base case (BTRE 2006a)
- for the domestic aviation sector, BITRE Base Case 2007 has a very similar long-term growth rate for the air transport task as Base Case 2005 (4.9 per cent per annum growth in total domestic passenger kilometres over 2000 to 2020, versus 5 per cent per annum over these two decades in the 2005 projections). However, the current base case has slightly lower projected growth in aviation emissions (with the updated base case estimates increasing by around 30 per cent between 2007 and 2020, while Base Case 2005 forecast close to 36 per cent). This is largely due to the new scenario assumptions, which include significant new aircraft purchases that accelerate the increasing efficiency (in terms of fuel consumed per seat kilometre available) of the fleet.

The population and income (real GDP) projections used for Base Case 2007 are very close to those assumed within *Base Case 2005* and *2006*, though slightly higher by the end of the projection period (with the 2020 forecast of real GDP 0.3 per cent higher in the current base case, and expected 2020 national population 1.1 per cent higher).

The fuel price projections used for the Base Case 2007 estimates are substantially higher than those used for Base Case 2005 (though quite similar to those used for the unpublished 2006 base case results, with the projected crude oil prices in the current 'reference' scenario being on average around 2 per cent lower than those of Base Case 2006). As was the case with the three base case studies preceding this update, fuel price projections are derived from long-term projections of crude oil prices by the US Energy Information Administration (EIA), using their (then current) projections in *Annual Energy Outlook 2007* (EIA 2007a). For the base case input assumptions regarding crude oil prices, see the fuel price section of the following chapter on model sensitivity tests (and Appendix Table A20). More recent EIA projections feature considerably higher oil price forecasts, and work incorporating these revised trends (along with updated GDP and population forecasts) into the transport projections is on-going.

Generally, oil price rises will cause declines in most transport indicators, but the effects will vary between modes. For example, in the road sector, increases in the price of petrol will tend (in the absence of any other effects) to decrease travel in private cars, while serving to increase the passenger market share of competing modes (such as bus or rail travel). Some Australian cities have seen particularly strong patronage growth on their public transit systems over the last couple of years, probably in part due to higher than average petrol prices.

If price changes are sustained over the medium-to-longer term, then consumer choices in vehicle purchases will also be affected (higher fuel prices tending to encourage the purchase of more fuel efficient vehicle models, as appears to be the case in the Australian car market over the last few years). Fuel price increases will also have some impact on freight demand levels, through the subsequent rises in freight rates to meet the higher fuel input costs. Trends in future aviation demand will also be quite sensitive to movements in the price of jet fuel, since alternative fuels for the aviation sector are currently very limited.

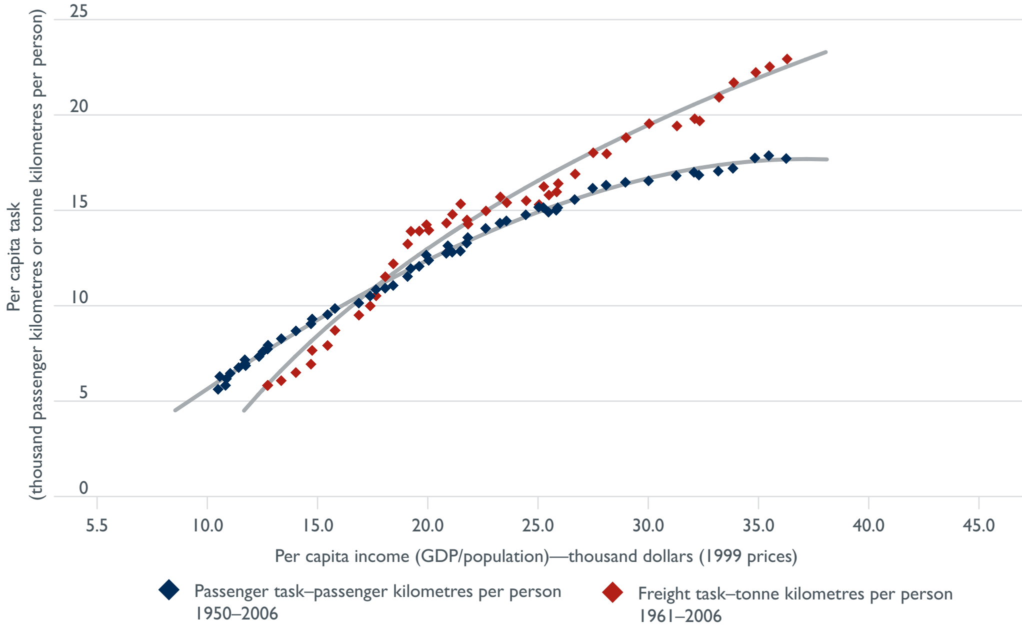
An important relationship underlying BITRE projections of transport task trends is the connection between rising income levels and per capita travel. Figure 3.1 (similar to Figure 2.3) plots approximately five decades of per capita Australian passenger and freight movements against average income levels.

Referring to Figure 3.1, it is noticeable how the growth rate in the per capita passenger task (passenger kilometres per person) has reduced in recent years (right-most points on the curve), especially compared with past very high growth in travel (for values on the left-hand side on the curve—roughly corresponding to the 1950s, 1960s and 1970s). Basically, as income levels (and motor vehicle affordability) have increased over time, average travel per person has increased, but at a decreasing rate. The data suggest there are limits to how much further average per passenger travel will increase. Eventually people are spending as much time on daily travel as they are willing to commit—and are loath to spend any more of their limited time budgets on yet more travel, even if incomes do happen to rise further.

Per capita urban daily passenger travel exhibits an even flatter relationship with average household income than national average per capita travel, as much of the recent slight upward trajectory in national total average per capita travel, exhibited in Figure 3.1, is essentially due to continuing strong growth in air travel (with its inherent advantages in reducing travel time spent per kilometre).

So future increases in Australian passenger kilometres travelled are likely to be more dependent on the rate of population increase, and less dependent on increases in general prosperity levels. Since this saturating relationship between increases in annual passenger kilometres per person and per capita income is even stronger for urban travel, such curve-fitting implies that saturation in per person urban travel could be virtually achieved in Australia by around 2020. Thereafter, population increase will tend to be the primary driver of increases in travel in Australian cities. Yet, at least until then, income increases will likely continue to add to per capita travel, and total passenger travel will tend to grow at a faster rate than population. Growth in per capita personal travel is thus likely to be lower in the future than for the long-term historical trend.

Figure 3.1 Relationship of Australian per capita freight and passenger movement to per capita income levels



Sources: BTRE (2002a, 2006a, 2007a), Cosgrove and Gargett (1992, 2007) and BITRE estimates.

Also note, as mentioned earlier, that this decoupling of income levels from personal travel trends is not apparent in the current freight movement trends. Tonne kilometres (TKM) performed per capita are still growing quite strongly and even though the freight trend curve of Figure 3.1 is slightly concave, there is no saturating tendency evident yet. Eventually this trend curve will have to shallow off too, over the longer term; but even though there are signs of saturating trends in freight movement within the UK and some other European countries (OECD 2006), there is no sign of it occurring any time in the near future for Australia. Growth in freight and service vehicle traffic is therefore projected (over at least the next decade or so) to be substantially stronger than for passenger vehicles.

Utilising the derived functional forms (such as those in Figure 3.1, relating per capita travel levels with income trends), Australian Bureau of Statistics (ABS) population projections, and the BITRE suite of transport demand models, the base case projections (to 2020) were prepared for the major aggregate task levels (for future trends in passenger and freight movement) and the likely modal split. The 2007 base case transport forecasts used population growth trends from the ABS mid-range long-term projections (see ABS 2005a, 2006c, 2007a), then available, where national population by 2020 had been forecast to reach about 23.7 million persons, with a total metropolitan population of around 15.2 million persons.

Most of the projection methods rely on using the historical trend data to determine functional or econometric relationships between growth in a particular transport task and relevant income level or price changes—either constant elasticity values (typically for tasks not exhibiting constraints in their growth behaviour) or curve-fitting (typically for saturating trends, such as for the per capita passenger tasks plotted in Figures 2.3 and 3.1). The aggregate tasks projected by these methods are then split into finer modal subdivisions, based on market share competitiveness models—derived using historical data, typically incorporating generalised cost parameters, which take account of average travel times for the various modes, direct expenses such as fuel prices and fares and allow for feedback effects from expected congestion levels, to play a part in travellers' mode choice decisions.

Road transport modelling

As mentioned previously, passenger travel per person (and in particular, car travel per person) can be modelled as a saturating curve with respect to real Australian GDP per person (where a 'logistic' curve formulation is used for aggregate modelling, and various polynomial functions with similar asymptotic tendencies have also been fit to the travel patterns of individual urban areas—see Cosgrove and Gargett (2007), BTRE (2002a) and BTRE (2007a) for more details.

Once the overall level of the likely saturation (in per capita vehicle travel, for the relevant area being modelled) is set, by considering either:

a. a structural equation for the particular mode or vehicle type's activity level (such as shown in Figure 2.3); or

b. the vehicle type's share of an aggregate saturating trend (that is split according to the mode share competitiveness models)

then adjustments to the trend are made using econometric models (e.g. allowing for price effects on new vehicle sales and average vehicle utilisation).

Projections of average car utilisation (kilometres per car per annum) were estimated using the trend in annual GDP growth, trends in household size and ownership of vehicles, and projected changes in the proportion of the population of working age, as a proxy for a variety of demographic factors that tend to affect average VKT (such as the average age of the population and the proportion of the population of driving age).

This initial estimated trend in VKT per car was then combined with the initial estimate of VKT per person (from the logistic formulation) to give a starting point trend for cars per person to 2020.

These initial trends estimates were then modified (where the Fuel_Car submodule of BITRE CARMOD uses an iterative procedure), adjusting for changes in vehicle prices over time and for projected fuel price changes, to derive adjusted (equilibrium) trend estimates for Australian car ownership, average VKT per car, and average per capita car travel.

CARMOD then calculates the vehicle fleet stock dynamics over the projection period, and derives the necessary level of new vehicle sales to meet this projected (equilibrium) level of Australian motorisation and thus the resulting fleet fuel efficiency, using the projected fuel intensities (L/100 km) of the new cars (from the technology subcomponent of the model).

Though the estimation process is dependent on the chosen elasticity values within the models, the final utilisation trends derived by this formulation are not highly sensitive to variations in those elasticity values, since car travel is relatively inelastic. Also, the logistic curve for per capita car travel exhibits slowing growth over the projection period and is quite flat after about 2015— meaning that projected values for car use beyond that point show diminishing response to income increases, and growth in total car VKT becomes progressively closer to population growth rates.

Transport demand tends to be fairly inelastic with respect to fuel prices. Even though the cost of fuel is an important contribution to overall transport costs, it tends to be overshadowed by other effects. The total *generalised* cost of motoring is a combination of the value of in-vehicle travel time, trip fuel costs, other operating costs (such as depreciation and maintenance), parking fees and tolls and network access charges (such as vehicle registration) of which fuel prices tend to comprise only a small proportion of the total.

Even though recent high oil prices have served to slightly dampen some elements of transport demand, they do not appear to have made a large impact on aggregate Australian transport emissions (with total domestic transport emissions still rising during 2006, a year with rapid fuel price rises). The recent prices do appear to have been high enough to cause a temporary pause in the growth of total private vehicle travel, with sales of automotive gasoline (petrol) actually falling slightly during the 2006 financial year. However, during the early stages of 2007, petrol sales roughly returned to trend growth rates (until further oil price rises and the economic slowdown during 2008, subsequent to the preparation of these projections, lead to another pause in fuel sales growth).

Higher petrol prices also seem to have influenced recent vehicle purchase patterns by Australian motorists, with new sales of large passenger cars down by nearly 20 per cent in 2006 (i.e. new large sedan sales, with new 4WD 'All Terrain Wagon' sales only decreasing slightly in 2006, and remaining close to 23 per cent of total passenger vehicle sales). Sales of small passenger cars and (highly fuel efficient) petrol-electric hybrid motor vehicles have been growing strongly—also probably influenced by the high fuel prices—with new small car sales increasing by about 20 per cent in 2006, and new hybrid vehicle sales roughly quadrupling over the last three years.

The short-term, or immediate, price elasticity of fuel demand appears to be in the range of about –0.1 to –0.3 for passenger vehicles (with a median value of about –0.16). The literature normally quotes values of between about –0.3 to –1.0 for long run petrol price elasticities (median value about –0.45), with the longer term values generally being higher than the short term, as certain behavioural effects (such as motorists' purchase choices moving to more fuel efficient vehicles) have time to impact on total fuel use.

Regarding the issue of whether the price responsiveness of fuel use may have altered in recent times (e.g. due to the sharpness of the 2005 and 2006 petrol price rises), the high price levels have not really held for a long enough period yet to allow any robust fitting of new elasticity values (i.e. to see if the new price levels have altered the historical elasticity values). Average elasticity values are, however, unlikely to have altered significantly, since the recent high prices are not greatly different, in real terms, from some other peaks in the past. Also, even though total Australian petrol sales did fall somewhat further in 2006 than a standard lower-bound short-term elasticity (of about –0.1) would imply, the fall was within the standard range (quoted above) for such short run values (and could even be consistent with an immediate responsiveness level of as low as –0.15 for total automotive fuel use, if allowance is made for the recent strong rises in LPG sales). A comprehensive summary of the literature in this area—across a wide variety of elasticity studies and their published values—has recently been completed by Todd Litman (from the Victoria Transport Policy Institute, see Litman 2009).

Prices for petroleum fuels, in real terms, will likely remain substantially higher than average prices between 1990 and 2000, at least for the near-to-medium term. The Base Case 2007 projections were based on the assumption that high oil price levels would eventually moderate somewhat, such that crude oil prices, in real terms, had been forecast to return to a medium-term average of about US$50–55 per barrel (at 2004 prices) after about 2010. As mentioned earlier, incorporating more recent (substantially higher) oil price forecasts from the international energy agencies is on-going.

The BITRE models also allow for the greenhouse effects of increasing traffic congestion levels within major urban areas (see BTRE 2007a). Congestion imposes significant costs on society, with interruptions to urban traffic flow lengthening average journey times, making trip travel times more variable, and making vehicle engine operation less efficient. This leads not only to higher rates of fuel consumption, than would otherwise have occurred, but also to poorer urban air quality (with vehicles operating under congested conditions typically emitting far higher rates of air pollutants than under more freely flowing conditions, resulting in not only even higher greenhouse gas output, but also higher health costs to the community).

The BITRE Motor Vehicle Emission suite (MVEm) estimates a wide range of pollutant emissions by vehicle type. The Cong_Car submodule of BITRE CARMOD (which has been slightly revised since BTRE (2007a) was completed) allows the emission models to estimate the likely effects of future urban traffic congestion levels (i.e. serving to raise both average fuel consumption and noxious emission rates) on a city-by-city basis.

The dynamic fleet models (coupled to the Cong_Car model) use an iterative procedure for each projection year (starting with an initial estimate of car use, average fuel intensity and passenger mode split, from the structural and econometric modelling already described):

- Allowing for new vehicles entering the fleet to gradually improve the average fuel efficiency of the respective vehicle stocks (where, over the longer term, decreases in average fuel consumption serve to lower the cost of motoring and encourage somewhat higher average VKT, negating a portion of the fuel savings gained from the original fuel efficiency improvement).

- Allowing for the projected growth in vehicle stocks and total VKT in each major metropolitan area to increase traffic volumes. When combined with an assumed rate of future road construction, this gives projections of average network volume-to-capacity (V/C) ratios for each Australian capital city (where a feedback loop then calculates the effect on average network speeds, for the V/C ratio increases, and the consequent increases in average fleet fuel intensity and any dampening of peak travel demand due to the increased travel times).
- After allowing for the initial feedback of an element of increasing peak traffic being restrained (through forgone travel or through trip timing decisions leading to peak-spreading), the next iteration of the model allows for modal choice changes where the extra delays from the growing congestion can cause some of the motorists to move to bus or rail commuting. This new set of values for modal tasks is then passed back to the first stage of the model and the process repeated until an equilibrium level (for future travel on each mode) is reached.

The modelled equilibrium values for future vehicle travel and average fuel consumption rates across the networks (derived from the feedback modules) are then passed onto the emission models (MVEm), which contain all the detailed emission factors (by vehicle type, age, condition, area of operation, technology type, fuel type, etc) for converting activity data into emission projection estimates.

The resulting greenhouse gas emission estimates for the road sector (in direct CO_2 equivalent values) are given in Table 1.1 (with more detail provided for projections of road task levels, road vehicle efficiencies, and emissions by different gas species, in Appendix Tables A4 to A10, A12, A14, A16, A18 and A21 to A24).

Consistency with the AGO/DCC Inventory values

Many of the emission factor details contained in the BITRE MVEm suite are partially redundant for this particular projection exercise, since their level of detail is primarily required for deriving robust estimates of noxious pollutants for urban areas, to evaluate the impact on urban health and amenity. Greenhouse gas totals for transport, however, are dominated by the CO_2 output from vehicle fuel use, the estimation of which is primarily dependent on the carbon content of the various transport fuels (since full carbon combustion is the standard methodological assumption).

The fuel carbon content values (in terms of grams of CO_2 emitted per megajoule of fuel consumed), both for this study and for the previous base case projection studies, have been taken from the National Greenhouse Gas Inventory (NGGI) transport workbooks—the most recent versions having been published by the AGO in late 2006: NGGIC (2006a), *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005, Energy (Transport)*; and the DCC in late 2007: NGGIC (2007), *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006, Energy (Transport)*.

Note that BITRE bottom-up emission aggregates tend to differ to some extent from the emission estimates contained in the AGO/DCC NGGI publications released so far. The BITRE estimation methodologies and emission factors are substantially more detailed than the default methods of the NGGI methodology workbooks, not only on the side of emission speciation and emission rate determination, but also dealing with activity level determination. This is especially so concerning analyses of: inconsistencies in reported transport activity, vehicle stock statistics and fuel data; of breaks in time series; and of standardisation across different collections of major surveys—such as the ABS *Survey of Motor Vehicle Use* values (e.g. see ABS 2006e).

For many years, BITRE had not fully agreed with the carbon content values (grams CO_2 per MJ), for automotive fuels, contained in the NGGI methodology workbooks—in particular, estimating that Australian CO_2 emissions from petrol consumption were being underestimated by at least a couple of per cent, due to a value for average (automotive gasoline) carbon content that appeared to be too low (e.g. see NGGIC 1998a, 1998b and 2005).

However, for the most recent transport workbooks of the National Greenhouse Gas Inventory Committee (NGGIC 2006a, 2007), there have been a variety of revisions to the default emission factors—including to the carbon content values—and BITRE regards this current set of gCO_2/MJ values (see Appendix Table A29) to be considerably more credible as Australian averages than those in the previous AGO methodology workbooks (such as NGGIC 2005).

Another significant update in the new NGGI transport workbooks is the revision of the N_2O emission factors (particularly those assigned to passenger motor vehicles fitted with three-way catalytic converters). Some of the nitrous oxide emission factors within the last few versions of the NGGI methodology workbooks (e.g. NGGIC 2005) have been anomalously high, in some cases as much as three times higher than that expected by BITRE (based on data presented in BTCE (1995a) and US Environmental Protection Agency 1998 and 2002). For historical year values contained in the BTRE Base Case 2005 results, this issue probably accounted for a major part of the divergences between the then NGGI estimates (for national direct CO_2 equivalent emissions) and BITRE's estimates (BTRE 2006a).

As for the CO_2 emission factors, the updated N_2O emission rates reported in the later NGGI transport workbooks (such as NGGIC 2006a) appear more realistic and robust than those in earlier issues and now give fleet average output values that are significantly closer to the values obtained from the detailed BITRE emission models (though with one of the remaining differences between the current NGGI workbook methods and aggregating BITRE MVEm results, being that the NGGIC methodology does not currently include any deterioration factors for N_2O emission rates, where the evidence tends to suggest that N_2O output increases as the catalyst in catalytic converters degrades over time).

In general, there is now a fairly close accord between the default average emission rates within the NGGI transport workbooks (NGGIC 2006a, 2007) and fleet averages obtained using the disaggregated BITRE emission models.

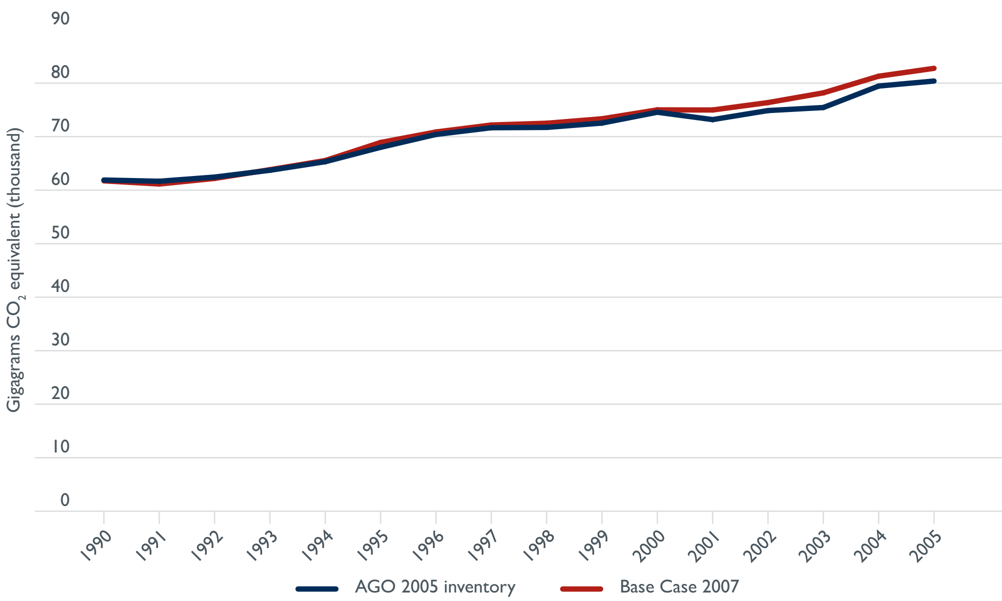
The remaining differences between BITRE estimates of total direct CO_2 equivalent emissions from the civil domestic transport sector and those of the most recent National Greenhouse Gas Inventory available at the time of this study (see AGO 2007a) relate primarily to issues concerning various fuel statistics (including problems concerned with allocating how much of total energy sales are consumed by domestic transport activities).

The *National Greenhouse Gas Inventory 2005* (AGO 2007a) derives an estimate of 80.4 million tonnes (of CO_2 equivalent *direct* emissions from energy end use) for the 2005 greenhouse contribution of the Australian civil transport sector. This compares reasonably closely with the BITRE estimate for the 2005 financial year (see Table 1.2) of 82.8 million tonnes (direct CO_2 equivalent, excluding carbon emissions from the combustion of biofuels), yet this roughly 3.0 per cent difference in emission totals is considerably larger than that for most years that the NGGI has so far evaluated (see Figure 3.2).

Over the 16 years, 1990 to 2005, BITRE and NGGI transport emission aggregates have been relatively consistent for most years (see Figure 3.2), with only more recent years' values starting to show clear divergences (and with the gap most noticeable for the years 2003 to 2005).

A reasonable level of overall correspondence is to be expected, since BITRE's emission estimates are done on a consistent sectoral definition to the NGGI, and the basic approach of the NGGI is also roughly equivalent (though on a much more aggregate level and using much lower detail in its calculation processes) to the BITRE bottom-up methodology. Most remaining differences between the two aggregate emission series (after allowing for any slight emission factor variations) appear to be due to fuel sales accounting issues.

Figure 3.2 Comparison of BITRE historical estimates for aggregate transport emission levels with the 2007 revision of the National Greenhouse Gas Inventory, 1990–2005



Note: Emission estimates relate to energy end use by domestic civil transport, and exclude CO_2 released from the combustion of biofuels.

Sources: AGO (2007a), BTRE (2006a), and BITRE estimates.

The NGGI emission estimate levels are largely determined by the annual energy use estimates published by the Australian Bureau of Agricultural and Resource Economics (ABARE). Time series data for sectoral energy use have been derived by ABARE, based on their Fuel and Electricity Survey (FES) and the former DITR's collation of petroleum sales data from the major fuel suppliers—noting that responsibility for fuel sales data now resides with the Department of Resources, Energy and Tourism (RET). Though these are also primary data for the BITRE emission estimation processes, BITRE's methods use a variety of aggregate transport activity and economic data sources as well, which can occasionally serve to crosscheck (at least on an order-of-magnitude basis) level shifts or trend changes in the fuel use values.

Though the BITRE (time series) estimates of energy consumption for domestic transport generally agree well with ABARE values (and thus the NGGI results), there are occasionally a few areas in which they differ.

One main difference concerns the allocation of total air and water transport fuel consumption to the domestic and international sectors, where a proportion of domestic aviation and shipping tasks are now undertaken by international craft. Essentially, the BITRE estimation methods reallocate (to the *domestic* transport sector) a portion of fuel sales recorded to international bunkers and international aviation, based on estimated total domestic task levels (i.e. both by domestic carriers and international vessels or aircraft). This effect, however, is not usually a large one and does not explain the size of the divergence between the NGGI and BITRE estimates for recent years.

Another complication concerning the precise allocation of total fuel sales to domestic civil transport is due to military fuel consumption. The quantification of fuel consumption by military transport has improved over time, especially since the Department of Defence started providing fuel use statistics to the Commonwealth's energy use audits of Australian Government operations (e.g. see AGO 2006a). However, even if total military fuel use is known accurately for a particular year, a number of uncertainties generally remain; concerning exactly where in the recorded fuel sales data that energy use will appear (e.g. some of the military fuel use will not be consumed in transport machinery, but in combat vehicles or generators; some of the fuel will be bought domestically but used overseas, while some will be purchased off-shore; a portion of the total fuel sold to the Department of Defence is not even consumed by the Australian military, but is on-sold to allied forces). Yet, such uncertainties notwithstanding, this issue is generally a fairly minor one—especially when compared with the magnitude of national aggregate fuel consumption (similar to the above case of the international-domestic fuel use allocation)—and also does not serve to explain the magnitude of the observed divergence.

The major effect on the current BITRE and NGGI differences appears to be due to possible irregularities, or definitional intricacies, in the current sectoral subdivisions of total fuel sales within the ABARE energy use time series. (The latest values for these time series available at the time of this study's preparation, were at this web reference: http://www.abareconomics.com/interactive/energy_july07/index.html).

Even following recent revisions to the ABARE series, there still seems to be one key anomaly in the sectoral trends for transport energy use; and it concerns the proportion of total ADO (automotive diesel oil) sales that are used by on-road vehicles.

The proportion of national ADO consumption due to road transport climbed steadily throughout the 1970s and 1980s, growing from about a quarter of total sales in the mid-1970s to roughly half by the late 1980s, and remained reasonably stable thereafter. This proportion has averaged close to 52 per cent over the last two decades and appears to have reached a maximum value in 2002 (for both BITRE and ABARE estimates) of about 54 (± 1) per cent.

However, recent ABARE sectoral statistics (see 'Table F' data on the ABARE web-site) have the proportion of on-road diesel use falling quite sharply from 2003 onwards, with results for the 2006 and 2007 financial years implying road sector contributions (at about 46 per cent of total sales) lower than at any time since the early 1980s. The current strong growth in the raw materials export market will tend to have contributed to rising energy consumption by the mining and bulk rail sectors, and this could lead to some decline in the road share of ADO use (and the BITRE trend estimates do exhibit a slight drop in the road diesel proportion, from a value of 54.4 per cent in 2002 to a preliminary estimate for 2007 of 52.8 per cent). Yet BITRE is not aware of any other aggregate trend indicators consistent with the magnitude of the sharp declines in the road diesel share exhibited by the ABARE estimates for 2003 to 2006.[1]

The result is a divergence between BITRE and ABARE estimates of road transport ADO use for the last few years which, furthermore, appears to account for most of the gap between BITRE and NGGI historical values for 2003 to 2005 national transport emissions, and results in a difference of around 15 per cent for the currently estimated 2006 road ADO values. If the weakening in road ADO growth within the current ABARE figures happens to reflect actual activity, then the next update of the BITRE demand models will have to be recalibrated to allow for the significantly lower freight movement level implied. Alternatively, if further revisions to the ABARE time series happen to move the estimated proportion (of road ADO use) back towards the long-term historical average, then the NGGI values for aggregate transport CO_2 emissions over the last few years will need to be revised upwards (probably by about 2–3 per cent).

Business-as-usual assumptions

As specified previously, the current BITRE Base Case 2007 uses a 'business-as-usual' scenario that makes some adjustments for behavioural or technical trends possibly affected by any of the various emission abatement measures already undertaken by Australian governments by mid-2007.

To give an indication of how much this base case scenario specification might differ from results using a purely BAU projection scenario (i.e. one that does not explicitly include the effects of any government abatement measures), this section of the report also presents some rough estimates of aggregate transport emissions using a BAU trend that attempts to carry on from the average sectoral conditions that held pre-2000.

1. Note that an inconsistency within the ABARE datasets could be involved in this estimation issue, where the original values released for national use of ADO over the 2005 financial year were different in two of the main ABARE historical data-tables. ABARE 'Table F' then quoted substantially higher ADO consumption for the 2003 to 2005 years than values given in their 'Table K' listing. The July 2007 update to these tables essentially fixed the divergence for the 2005 financial year values, and more recent (2008) updates exhibit only a slight divergence for the 2007 financial year values—but, at the time of this report's writing, there still remained around a 5 per cent gap between Table F and Table K's provided values for 2003, 2004 and 2006 (financial year) national ADO usage.

The current BITRE base case scenario takes account of fuel efficiency targets, for the National Average Fuel Consumption (NAFC) rating of new vehicle sales, which are part of the Government policy measures comprising the Environmental Strategy for the Motor Vehicle Industry (ESMVI). The efforts of the motor vehicle manufacturers, in endeavouring to meet the negotiated (voluntary) NAFC targets, are predicted to accelerate trend improvement in the average fuel efficiency of new light vehicle sales (not only for passenger sedans, but also for all-terrain wagons (ATWs) and LCVs, including the 4WD pickup/cab chassis section of the light commercial vehicle fleet).

These 2007 projections also allow for hybrid petrol-electric vehicles to gain a growing market share of new car sales over the forecast period (where the fuel intensity of such hybrids can be as low as half that of an equivalent-sized standard vehicle). Hybrid sales are projected to account for almost 10 per cent of annual new car sales by 2020 (though numbers of 'plug-in' hybrids—petrol-electric vehicles with larger than current batteries, that can be charged from electricity outlets—are assumed to be fairly insignificant before 2020).

Recent high levels of new vehicle sales (especially for smaller cars) also mean that the average penetration rate of the latest fuel efficiency technologies has been further accelerated (and also that vehicle stock projections in these latest projections are higher than those for preceding base case results). Note that, particularly for heavy vehicles, meeting future Australian Design Rules (ADRs) to limit noxious emissions could involve possible fuel efficiency overheads.

As well as the ESMVI targets, other incentives or policy measures that have a bearing on possible abatement of greenhouse gas emissions from Australian transport include:

- a focus on various Travel Demand Management approaches and other communication or education campaigns aimed at facilitating a voluntary change in behaviour towards more sustainable modes of travel such as walking, cycling and public transport.
- biofuels sales targets where the sale of ethanol blended transport fuels has grown strongly over the last few years, aided by Government grants to help with the infrastructure costs of converting retail service stations to handle E10 (10 per cent ethanol, 90 per cent petrol) blends. While there were only about 70 service stations selling ethanol blends in Australia in mid-2005, there were over 250 by mid-2006, and the number of outlets is continuing to grow rapidly (with the sales of ethanol and biodiesel both expected to show quite strong medium-term growth; though the magnitude of future growth will be partially dependent on relative feedstock prices and availability—such as those of grain for ethanol production—and on the overall benefits of using such replacement fuels, considering not only full lifecycle emissions performance, but also economic and environmental flow-on effects due to any required land-use changes)
- the Alternative Fuels Conversion Programme (AFCP), which helped fund the conversion of some heavy commercial vehicles to run on natural gas (NG) or liquefied petroleum gas (LPG)
- various actions taken by state and territory governments under the National Greenhouse Strategy (NGS), such as integrating urban land use and transport planning to enhance transport system efficiency, improving public transport services, and increasing support for walking and cycling

- a LPG rebates scheme, where in August 2006, the Government announced a rebate for the purchase of new LPG vehicles for private use. The scheme (contributing towards the purchase cost of a new factory-fitted LPG powered vehicle or towards the cost of converting vehicles to LPG for private use) would have served to slightly accelerate the penetration of LPG into the vehicle fuel market.

The Base Case 2007 scenario does not include any possible effects due to future policy measures, such as the proposed Carbon Pollution Reduction Scheme.

Table 3.1 and Figure 3.3 are provided to aid comparisons between the current base case trend and that of a more *pure* BAU scenario, where the 2007 base case results (for the aggregate transport sector) are contrasted with estimates from a 1990s BAU[2] scenario (i.e. where, in particular, the estimated effects of the specified abatement measures are not included). For example, for car fuel use, the 1990s BAU scenario extrapolates from historical trends, and from motor vehicle industry product plans that were released prior to the ESMVI process, to obtain a possible fuel efficiency trend expected in the absence of the ESMVI targets (and of recent years' increasing fuel price trends).

Note that the values in Table 3.1 and Figure 3.3 include emissions due to the production of biofuels and to power generation for electric railways (since some of the measures will have impacts not only on energy end use but also on the levels of upstream energy use or fuel processing), and are therefore somewhat higher than the transport totals (direct CO_2 equivalent) given in previous report tables.

As can be seen from table 3.1, a central ('ballpark') estimate for the effects of post-2000 developments in average travel efficiency (essentially flowing from changes in vehicle purchasing decisions, partially due to increasing fuel prices, and from the various abatement measures makes a difference to the base case trend in the order of 2 million tonnes (direct CO_2 equivalent) by 2010. These rough estimates (of a '1990s BAU' adjusted series) use a combination of values provided by the AGO (on the expected emission reductions from certain projects) and, where possible, BITRE modelling of the alternative behavioural and technical trends.

It should be noted that the estimation of such trend adjustments is very approximate. In fact, since many of the measures involve either *voluntary* targets or methods such as communication and education campaigns, the identification (and quantification) of any actual impacts on transport activity is both difficult and highly inexact. Several of the identified measures have significant abatement potential but to what extent that potential is capable of being realised within the projection period will generally be rather uncertain. It is even possible that such measures will only have very limited impacts on aggregate emission levels. As a guide to the high uncertainty levels inherent in these calculations, Figure 3.3 uses 'error bars' to give indications of likely upper and lower bounds on the estimated '1990s BAU' trend line (in relation to the 2007 base case).

As mentioned earlier, Base Case 2007 uses a scenario of roughly stable oil prices over the projection period (to 2020).

2. Business-as-usual (BAU) essentially means, in this context, expected future developments based on continuation of the industry practices, consumer behaviour and trend efficiency improvements of the 1990s.

Table 3.1 Business-as-usual scenario projections for greenhouse gas emissions from Australian civil domestic transport, to 2020

Financial year	*BITRE Base Case 2007 (including net biomass and electricity generation emissions)*	*Trend adjusted to a '1990s BAU' scenario*
	(gigagrams of direct CO_2 equivalent)	
1990	63 224	63 224
1991	62 616	62 616
1992	63 685	63 685
1993	65 287	65 287
1994	66 983	66 983
1995	70 450	70 450
1996	72 353	72 353
1997	73 760	73 760
1998	74 077	74 077
1999	74 946	74 946
2000	76 702	76 702
2001	76 706	76 789
2002	78 100	78 265
2003	79 917	80 166
2004	83 005	83 339
2005	84 495	85 045
2006	85 300	86 074
2007	87 706	88 911
Forecasts		
2008	89 289	91 036
2009	91 636	93 622
2010	93 573	95 836
2011	95 239	97 853
2012	96 688	99 656
2013	98 088	101 368
2014	99 516	103 120
2015	100 952	104 888
2016	102 284	106 536
2017	103 611	108 187
2018	104 900	109 807
2019	106 329	111 574
2020	107 648	113 241

Notes: The '1990s BAU' values given are a 'central estimate' for the base case scenario adjusted to exclude changes to vehicle purchasing decisions following post-2000 fuel price rises and the effects of government measures (aimed at abating greenhouse gas emissions) that had already been implemented by the time of this study. (See Figure 3.3 for an indication of the uncertainty levels in this estimation process.)

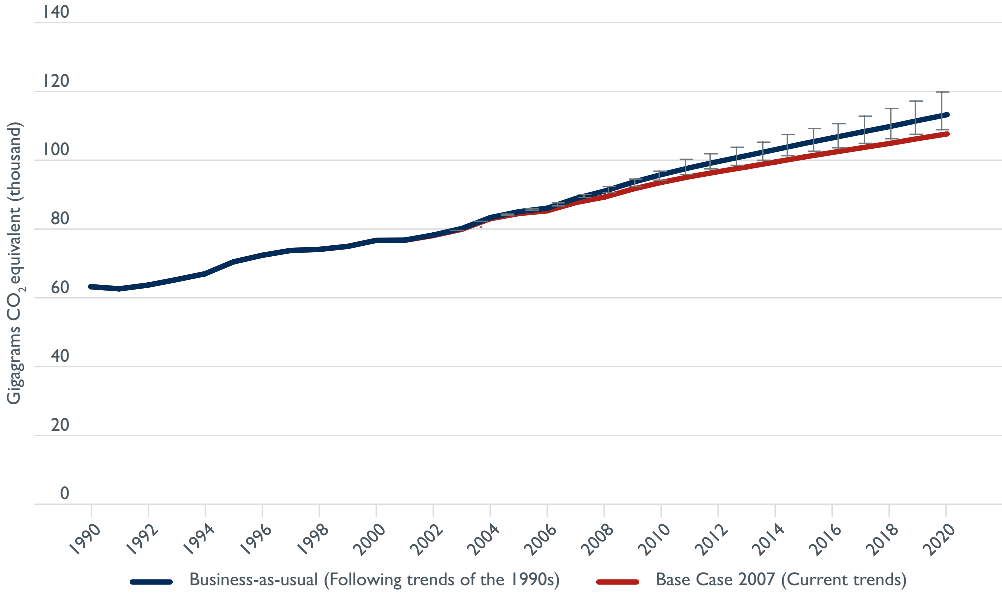
The base case scenario assumes that new vehicle fuel efficiency targets (ESMVI measure) will affect trends for all light vehicles and accelerate trend improvements (i.e. from what would have occurred in the absence of the vehicle manufacturer targets). The BAU scenario uses a continuation of earlier vehicle industry product plans, to give a trend assumed likely to have occurred in the absence of the ESMVI targets.

Emissions here include net biomass emissions (i.e. do not include CO_2 released from in-vehicle combustion of biofuels, but do include emissions due to biofuel production), and those due to all rail operations (i.e. include emissions from power generation for electric railways). With the exception of these two extra inclusions, the emission totals are otherwise still energy end use emissions, i.e. do not include other upstream fuel supply and processing emissions. (See Chapter 5 for some comparisons of full fuel cycle estimates.)

Emissions are direct greenhouse gas emissions only, carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: AGO (pers. comm. June 2007), BTE (1999a), BITRE (2002a, 2003a, 2006a), Energy Strategies (2005) and BITRE estimates.

Figure 3.3 Comparison of BITRE Base Case 2007 trend with estimated 1990s BAU trend for aggregate domestic transport emission levels, 1990–2020



Notes: Emissions here include net biomass emissions (i.e. do not include CO_2 released from the in-vehicle combustion of biofuels, but do include emissions due to biofuel production), and those due to all rail operations (i.e. include emissions from power generation for electric railways). With the exception of these two extra inclusions, the emission totals are otherwise energy end use emissions—i.e. do not include other upstream fuel supply and processing emissions—from domestic civil transport.

Error/uncertainty bars on 1990s BAU trend give likely upper and lower bounds for the aggregate effects of already implemented emission abatement measures.

Sources: AGO (pers. comm. June 2007), BTE (1999a), BTRE (2002a, 2003a, 2006a), Energy Strategies (2005) and BITRE estimates.

Chapter 4 Sensitivity analyses

The projected trends are sensitive to a variety of input assumptions in the projection modelling, such as future income and population growth, and the penetration rates of more fuel-efficient vehicle technology.

As a part of this update of the projections of transport sector emissions, the AGO requested that BITRE undertake sensitivity testing of the results to changes in the underlying assumptions. This chapter gives the results of various sensitivity tests, following the AGO specifications, that were conducted by BITRE. Sensitivity analysis was undertaken separately for each of variations in assumed future economic growth, population growth, fuel prices, the effects of future congestion levels and future fuel efficiency for new vehicles, and, as requested by the AGO, combination 'High' and 'Low' Scenarios (that alter all these input parameters simultaneously). The results of each of the sensitivity simulations are presented below.

Note that the different settings of the various underlying variables (such as economic growth) used in the sensitivity tests do not necessarily represent alternative 'probable' scenarios for future growth. They simply relate to value ranges, agreed with the AGO, to test the response of the base case results to variations in underlying assumptions.

Generation of demand by income and population levels

Table 4.1 shows the results, across the transport sector emission estimates, of assuming economic growth to be 0.5 per cent per year higher or lower than in the base case and population growth to be 0.1 per cent per year higher or lower than in the base case. The base case assumptions for population and economic growth are listed in Appendix Tables A1 to A3 (with average compound GDP growth projected to be around 2.84 per cent per annum over the period of 2000 to 2020). Note that the recent economic downturn occurred after the preparation of these projection results.

Overall, since car use is displaying signs of tending to saturate with regard to income, and since some subsectors are relatively independent of Australian economic growth (e.g. some commodity flows depend more on the economic growth of our major export markets than on local income growth), the effect on total emissions is somewhat muted. The subsectors most responsive to economic growth are road freight and aviation.

The income (real GDP) and population sensitivity analyses change total 2020 emission levels by approximately 5 per cent (up and down) from the base case. Under the Low Scenario aggregate emissions in 2010 are about 0.6 per cent below the base case. Under the High Scenario aggregate emissions in 2010 are about 0.6 per cent above the base case value.

Table 4.1 Low GDP and population sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 526	2 412	2 176	6 863	85 756
Forecasts					
2008	75 589	2 532	2 240	7 054	87 118
2009	77 428	2 631	2 302	7 262	89 250
2010	78 853	2 721	2 370	7 471	90 966
2011	79 959	2 795	2 414	7 663	92 307
2012	80 863	2 837	2 419	7 805	93 326
2013	81 681	2 879	2 427	7 931	94 301
2014	82 492	2 933	2 440	8 044	95 275
2015	83 311	2 980	2 451	8 139	96 228
2016	84 020	3 021	2 460	8 210	97 051
2017	84 717	3 057	2 462	8 275	97 843
2018	85 359	3 089	2 460	8 336	98 570
2019	86 133	3 123	2 460	8 397	99 434
2020	86 772	3 159	2 462	8 458	100 155

Notes: The 'low' scenario assumes a decrease of 0.5 per cent per annum in the base case values for real Australian GDP growth over the projection period, and a 0.1 per cent decrease in per annum population growth relative to the base case.

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a), BTRE (2007d, 2006a, 2003b, 2002a), VTPI (2007) and BITRE estimates.

Table 4.2 High GDP and population sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 610	2 415	2 177	6 872	85 853
Forecasts					
2008	75 934	2 545	2 245	7 091	87 517
2009	78 035	2 655	2 312	7 327	89 952
2010	79 748	2 757	2 384	7 566	92 001
2011	81 335	2 851	2 437	7 808	93 898
2012	82 897	2 920	2 453	8 020	95 678
2013	84 413	2 991	2 474	8 218	97 458
2014	85 973	3 077	2 501	8 408	99 296
2015	87 592	3 158	2 526	8 587	101 176
2016	89 163	3 237	2 550	8 744	102 993
2017	90 765	3 311	2 568	8 898	104 827
2018	92 368	3 384	2 582	9 052	106 658
2019	94 106	3 460	2 598	9 205	108 627
2020	95 760	3 541	2 617	9 362	110 511

Notes: The 'high' scenario assumes an increase of 0.5 per cent per annum in the base case values for real Australian GDP growth over the projection period, and a 0.1 per cent decrease in per annum population growth relative to the base case.

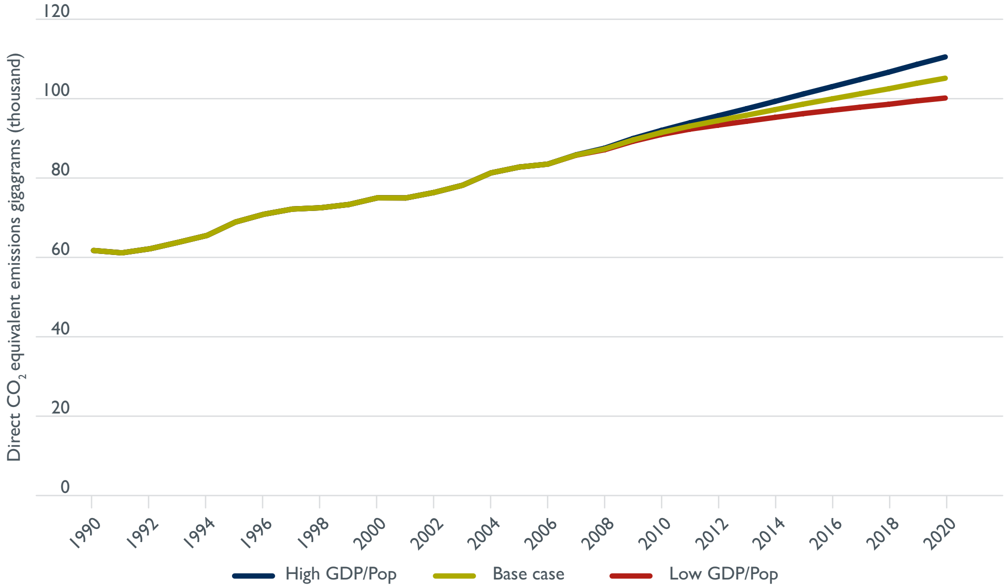
'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a), BTRE (2007d, 2006a, 2003b, 2002a), VTPI (2007) and BITRE estimates.

Figure 4.1 Sensitivity of total transport emission projections to GDP and population assumptions



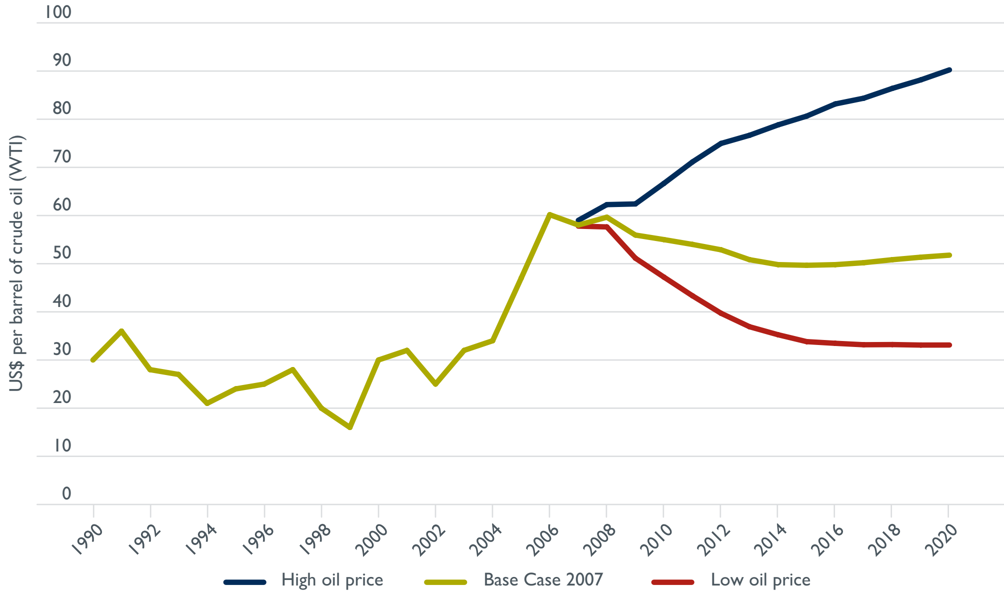
Sources: BTRE (2002a, 2003a, 2006a) and BITRE estimates.

Fuel prices

The Base Case 2007 projections, and these sensitivity analyses, were done before the strong oil price rises that commenced in late 2007, and therefore do not include allowance for the (historically) high crude oil prices attained during mid-2008.

Base case trends in fuel prices, and the high and low sensitivity assumptions, were based on long-term projections of crude oil prices by the US Energy Information Administration (EIA)—in their *Annual Energy Outlook 2007* (EIA 2007a)—supplemented with values from their short-term forecasting results at the time (EIA 2007b). BITRE Base Case 2007 uses estimates of real West Texas Intermediate (WTI) prices, with future values based on the EIA 'Reference Case' scenario trends. The high fuel price sensitivity is based on the EIA's then 'High Price Case' scenario and the low fuel price sensitivity on the EIA 'Low Price Case' scenario trend (EIA 2007a). These derived trends are shown in Figure 4.2 (with values given in the Appendix).

Figure 4.2 2007 projections of crude oil prices (in real terms, 2004 dollars)



Sources: BTRE (2007d, 2002a, 2006a), EIA (2007a, 2007b)—adjusting the calendar year US Refiner's Acquisition Cost values in EIA (2007a) data to financial year real WTI (West Texas Intermediate) values—and BITRE estimates.

Table 4.3 Low fuel price sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	Motor vehicles	Rail (non-electric)	Maritime	Aviation	Total
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 665	2 412	2 176	6 873	85 908
Forecasts					
2008	75 971	2 536	2 241	7 085	87 543
2009	78 237	2 635	2 304	7 325	90 144
2010	80 144	2 725	2 372	7 569	92 389
2011	81 908	2 802	2 418	7 812	94 460
2012	83 583	2 850	2 425	8 017	96 339
2013	85 119	2 900	2 438	8 202	98 116
2014	86 690	2 964	2 456	8 378	99 940
2015	88 387	3 019	2 471	8 545	101 874
2016	89 959	3 071	2 484	8 686	103 662
2017	91 604	3 118	2 491	8 826	105 510
2018	93 241	3 161	2 495	8 965	107 347
2019	95 071	3 206	2 499	9 108	109 383
2020	96 805	3 253	2 506	9 253	111 323

Notes: In the 'low' scenario, the crude oil price in 2020 is assumed to be around US$33 per barrel (WTI) compared with around US$52 in the base case.

'Motor Vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1995a), BTRE (2002a, 2006a, 2007d), EIA (2007a, 2007b) and BITRE estimates.

Table 4.4 High fuel price sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
		(gigagrams of direct CO_2 equivalent)			
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 412	2 417	2 177	6 858	85 637
Forecasts					
2008	75 381	2 547	2 245	7 048	86 911
2009	76 836	2 663	2 313	7 238	88 645
2010	77 772	2 773	2 388	7 423	89 850
2011	78 295	2 876	2 443	7 588	90 585
2012	78 637	2 952	2 459	7 708	91 024
2013	78 880	3 029	2 480	7 811	91 407
2014	79 097	3 121	2 507	7 900	91 771
2015	79 368	3 207	2 532	7 976	92 167
2016	79 441	3 291	2 555	8 022	92 340
2017	79 605	3 369	2 572	8 068	92 593
2018	79 597	3 448	2 586	8 103	92 656
2019	79 635	3 531	2 602	8 133	92 763
2020	79 402	3 622	2 621	8 153	92 580

Notes: In the 'high' scenario, the crude oil price in 2020 is assumed to be around US$90 per barrel (WTI) compared with around US$52 in the base case.

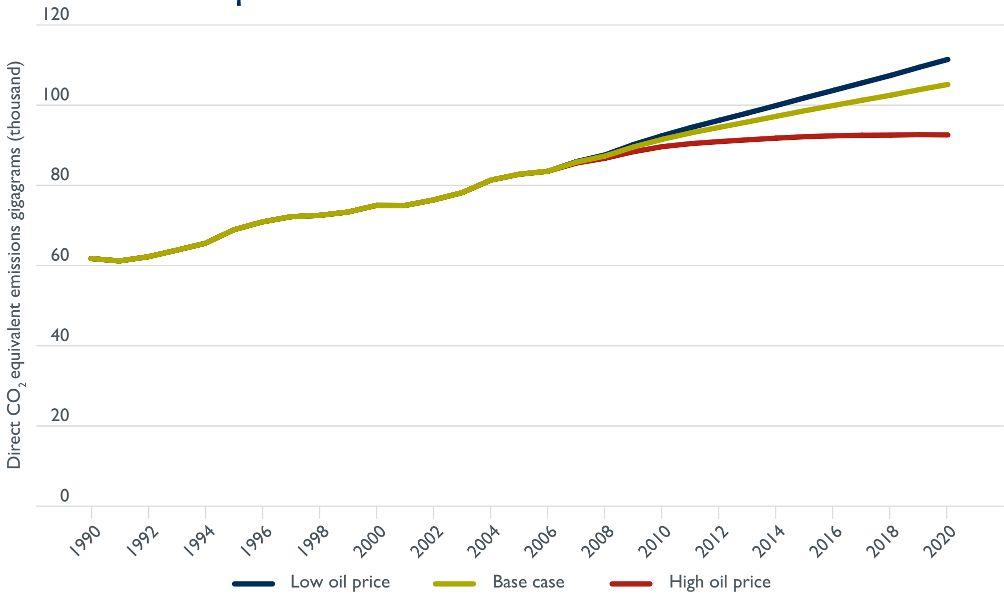
'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1995a), BTRE (2002a, 2006a, 2007d), EIA (2007a, 2007b) and BITRE estimates.

Figure 4.3 Sensitivity of total transport emission projections to fuel price assumptions



Sources: BTRE (2002a, 2006a, 2007d), EIA (2007a, 2007b) and BITRE estimates.

The oil price sensitivity results do not include the effects that petrol price fluctuations would have on the wider economy (e.g. with large scale rises tending to be inflationary) since such economy-wide interactions are beyond the typical scope of bottom-up modelling analyses. Since most transport activities are relatively inelastic with respect to fuel prices, the high and low scenario values for 2010 only vary, respectively, from the base case values by about 1.8 per cent below and 1.0 per cent above, with 2020 values, respectively, of about 12 per cent below and 6 per cent above the base case.

Congestion effects

Utilising methods developed for BTCE (1996b), and more recent work on metropolitan transport pollution (BTRE 2003c) and urban congestion impacts (BTRE 2007a), the base case incorporates allowances for urban traffic congestion effects on vehicle fuel consumption. The projected fuel efficiency penalty—from traffic delays and interruptions to traffic flow—varies considerably from city-to-city, depending on the particular network characteristics and the expected rate of population growth.

The 'high congestion' scenario assumes that the response of vehicle fuel intensity to increases in urban traffic congestion is 50 per cent stronger than in the base case model settings.

The 'low congestion' scenario assumes induced rises in average vehicle fuel intensity due to increases in urban traffic congestion are 50 per cent weaker than in the base case parameter settings.

Altering the congestion feedback parameters in the BITRE vehicle fleet models (by this variation of 50 per cent up and down) resulted in a variation of the 2010 base case values (for total transport emissions) of around 0.5 per cent. The changes to total 2020 emission levels were around 4 per cent from the base case level.

Table 4.5 Low congestion sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 530	2 413	2 176	6 867	85 766
Forecasts					
2008	75 604	2 539	2 242	7 071	87 159
2009	77 451	2 642	2 307	7 293	89 320
2010	78 888	2 738	2 376	7 515	91 068
2011	80 013	2 821	2 424	7 730	92 464
2012	80 943	2 876	2 434	7 904	93 558
2013	81 787	2 930	2 447	8 061	94 608
2014	82 624	2 998	2 466	8 208	95 659
2015	83 470	3 060	2 482	8 339	96 696
2016	84 209	3 117	2 497	8 446	97 607
2017	84 939	3 169	2 505	8 548	98 493
2018	85 615	3 219	2 510	8 649	99 318
2019	86 423	3 273	2 517	8 752	100 281
2020	87 101	3 329	2 526	8 856	101 113

Notes: The 'low' scenario assumes a 50 per cent weaker response of vehicle emissions to increasing traffic congestion than the base case.

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1996b, 1995a), BTRE (2007a, 2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 4.6 High congestion sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 606	2 413	2 176	6 867	85 842
Forecasts					
2008	75 916	2 539	2 242	7 071	87 470
2009	78 005	2 643	2 307	7 293	89 872
2010	79 704	2 739	2 377	7 518	91 884
2011	81 267	2 823	2 426	7 736	93 719
2012	82 796	2 879	2 437	7 914	95 414
2013	84 279	2 936	2 452	8 078	97 109
2014	85 806	3 007	2 473	8 233	98 858
2015	87 390	3 072	2 493	8 373	100 642
2016	88 922	3 133	2 510	8 491	102 357
2017	90 483	3 190	2 521	8 603	104 084
2018	92 041	3 244	2 529	8 715	105 801
2019	93 736	3 299	2 537	8 823	107 655
2020	95 339	3 358	2 548	8 932	109 412

Notes: The ‘high’ scenario assumes a 50 per cent stronger response of vehicle emissions to increasing traffic congestion than the base case.

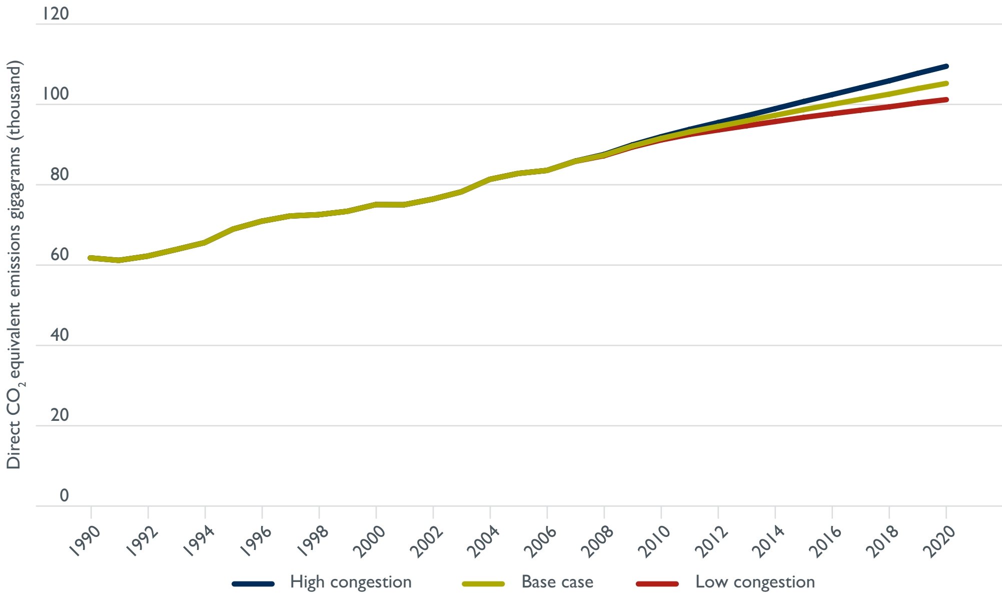
‘Motor vehicles’ include all road vehicles plus off-road recreational vehicles. ‘Aviation’ includes emissions from general aviation as well as airlines. ‘Maritime’ includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1996b, 1995a), BTRE (2007a, 2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Figure 4.4 Sensitivity of total transport emission projections to traffic congestion response parameters



Sources: BTCE (1996b), BTRE (2007a, 2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Fuel intensity

Altering assumed penetration rates for fuel-efficient technology (as per the assumptions detailed below) changes 2010 base case values (for total transport emissions) by slightly more than one per cent, and 2020 emission totals by approximately 6 per cent.

The 'low fuel intensity' scenario assumes that, by the end of the projection period:

- new passenger cars are 15 per cent more fuel efficient than for the base case trend improvement, and new LCVs are 10 per cent more fuel efficient than for the base case trend improvement
- the fuel consumption rate and average load parameters for rigid trucks change over time such that the average freight task efficiency of the fleet improves by 0.2 per cent per annum faster than the base case trend improvement (in megajoules per tonne kilometre terms)
- the fuel consumption rate and average load parameters for articulated trucks change over time such that the average freight task efficiency of the fleet improves by 0.5 per cent per annum faster than the base case trend improvement (in megajoules per tonne kilometre terms)
- the average fuel intensity for all other transport fleets is 10 per cent below the base case trend.

The 'high fuel intensity' scenario assumes that, by the end of the projection period:

- new passenger cars are 15 per cent less fuel efficient than for the base case trend improvement, and new LCVs are 10 per cent less fuel efficient than for the base case trend improvement
- the fuel consumption rate and average load parameters for rigid trucks change over time such that the average freight task efficiency of the fleet improves by 0.2 per cent per annum slower than the base case trend improvement (in megajoules per tonne kilometre terms)
- the fuel consumption rate and average load parameters for articulated trucks change over time such that the average freight task efficiency of the fleet improves by 0.5 per cent per annum slower than the base case trend improvement (in megajoules per tonne kilometre terms)
- the average fuel intensity for all other transport fleets is 10 per cent above the base case trend.

Table 4.7 Low fuel intensity sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 408	2 406	2 171	6 848	85 613
Forecasts					
2008	75 351	2 520	2 227	7 017	86 819
2009	77 119	2 614	2 284	7 215	88 862
2010	78 454	2 695	2 342	7 398	90 443
2011	79 527	2 756	2 373	7 558	91 693
2012	80 447	2 790	2 365	7 678	92 686
2013	81 264	2 823	2 361	7 780	93 614
2014	82 060	2 866	2 361	7 865	94 521
2015	82 849	2 902	2 358	7 935	95 395
2016	83 524	2 933	2 352	7 980	96 132
2017	84 171	2 956	2 338	8 016	96 817
2018	84 751	2 975	2 320	8 047	97 425
2019	85 423	2 995	2 302	8 075	98 121
2020	85 953	3 015	2 285	8 101	98 665

Notes: The 'low' scenario assumes approximately 10–15 per cent faster improvements (by 2020) in fleet fuel efficiency trends than the base case.

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 4.8 High fuel intensity sensitivity: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 730	2 420	2 181	6 887	85 997
Forecasts					
2008	76 189	2 558	2 257	7 126	87 831
2009	78 406	2 671	2 329	7 371	90 399
2010	80 288	2 782	2 412	7 634	92 660
2011	81 990	2 887	2 478	7 907	94 725
2012	83 589	2 964	2 505	8 139	96 580
2013	85 135	3 044	2 538	8 358	98 432
2014	86 712	3 138	2 578	8 574	100 334
2015	88 336	3 230	2 617	8 776	102 264
2016	89 888	3 317	2 655	8 956	104 109
2017	91 462	3 403	2 688	9 135	105 967
2018	93 019	3 487	2 718	9 315	107 805
2019	94 729	3 576	2 751	9 498	109 806
2020	96 332	3 671	2 788	9 686	111 704

Notes: The 'high' scenario assumes approximately 10–15 per cent slower improvements (by 2020) in fleet fuel efficiency trends than the base case.

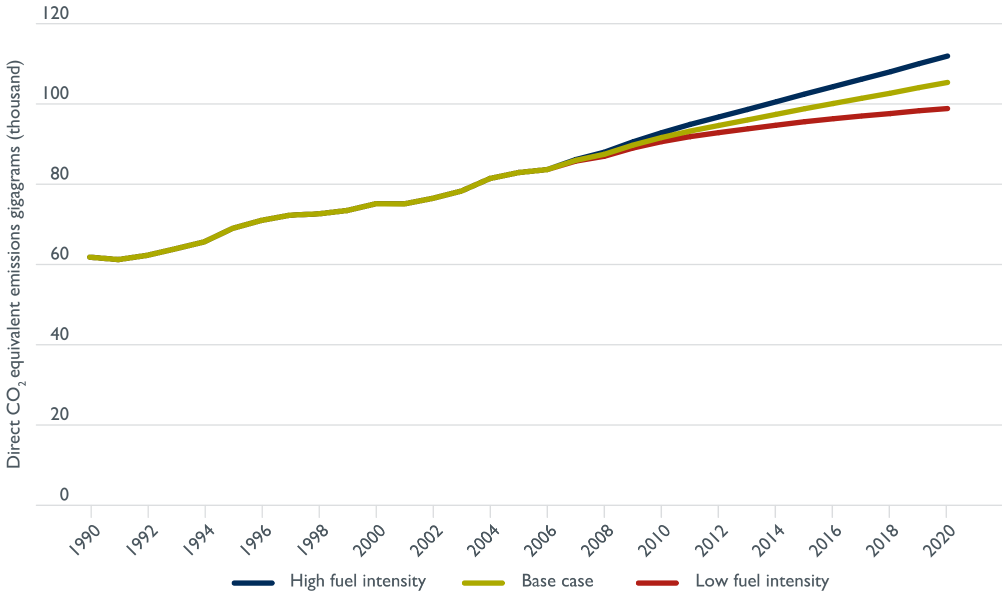
'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Figure 4.5 Sensitivity of total transport emission projections to fleet fuel intensity assumptions



Sources: BTCE (1996a, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

High and low combination scenarios

The high and low combination scenarios AGO requested demonstrate how much the projections alter if the major input assumptions are all varied together, yielding the highest and lowest potential transport sector greenhouse estimates (given the current base case model formulation and the sensitivity ranges specified in the preceding sections for the model inputs).

The Low combination scenario is the result of running the BITRE emission models using the combination of deviations from each of the preceding sensitivity scenarios that yields the lowest level of aggregate transport emissions (including the effects of low economic growth, low population growth, a higher rate of fuel intensity improvements than the base case, high oil prices and low urban congestion response). The low combination settings gave total 2010 emission levels of around 3.3 per cent below the base case, with total 2020 emission levels around 20.0 per cent lower than the base case.

Similarly, the High combination scenario uses the combination of sensitivity deviations that yields the highest level of aggregate emissions (based on high economic growth, high population growth, a lower rate of fuel intensity improvements than the base case, low future oil prices and high level of response to urban traffic congestion). The high combination settings resulted in total 2010 emission levels of around 2.9 per cent above the base case, with total 2020 emission levels around 17.5 per cent higher than the Base Case 2007 result.

Table 4.9 Low scenario—combined effects of sensitivity settings: greenhouse gas emissions for Australian transport, 1990– 2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 217	2 406	2 171	6 837	85 406
Forecasts					
2008	74 936	2 522	2 229	6 999	86 383
2009	75 960	2 606	2 279	7 138	87 595
2010	76 596	2 683	2 334	7 280	88 421
2011	76 683	2 740	2 363	7 386	88 615
2012	76 608	2 769	2 353	7 448	88 533
2013	76 402	2 796	2 345	7 489	88 356
2014	76 143	2 836	2 343	7 514	88 126
2015	75 812	2 868	2 336	7 515	87 787
2016	75 336	2 894	2 327	7 486	87 278
2017	74 757	2 912	2 310	7 443	86 633
2018	74 068	2 927	2 287	7 392	85 862
2019	73 416	2 942	2 265	7 331	85 118
2020	72 560	2 959	2 244	7 263	84 153

Notes: The 'low' scenario assumes the combination of all the previous sensitivity deviations that yields the lowest level of aggregate emissions.

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1996b, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table 4.10 High scenario—combined effects of sensitivity settings: greenhouse gas emissions for Australian transport, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
		(gigagrams of direct CO_2 equivalent)			
1990	54 790	1 733	2 387	2 833	61 743
1991	53 824	1 725	2 083	3 517	61 149
1992	54 557	1 676	2 142	3 817	62 191
1993	56 213	1 650	1 951	4 012	63 825
1994	57 696	1 783	1 817	4 245	65 538
1995	59 858	1 734	2 321	5 003	68 909
1996	61 266	1 687	2 445	5 491	70 874
1997	62 179	1 719	2 436	5 863	72 174
1998	63 336	1 747	2 135	5 318	72 504
1999	64 622	1 797	1 843	5 120	73 339
2000	65 928	1 863	1 926	5 352	75 003
2001	65 519	1 829	1 772	5 963	74 981
2002	67 449	1 914	1 792	5 347	76 367
2003	69 428	1 965	1 798	5 103	78 181
2004	71 970	2 109	1 923	5 337	81 295
2005	72 721	2 266	2 146	5 678	82 767
2006	72 878	2 338	2 085	6 303	83 506
2007	74 871	2 423	2 182	6 895	86 151
Forecasts					
2008	76 468	2 561	2 257	7 136	88 126
2009	79 252	2 691	2 338	7 433	91 341
2010	81 623	2 813	2 425	7 730	94 141
2011	84 050	2 931	2 495	8 045	96 996
2012	86 399	3 023	2 528	8 324	99 673
2013	88 739	3 116	2 567	8 593	102 392
2014	91 156	3 225	2 612	8 857	105 207
2015	93 697	3 332	2 658	9 114	108 136
2016	96 212	3 435	2 702	9 354	111 030
2017	98 834	3 537	2 742	9 597	114 028
2018	101 497	3 638	2 780	9 845	117 069
2019	104 378	3 745	2 822	10 100	120 345
2020	107 229	3 858	2 866	10 364	123 598

Notes: The 'high' scenario assumes the combination of all the previous sensitivity deviations that yields the highest level of aggregate emissions.

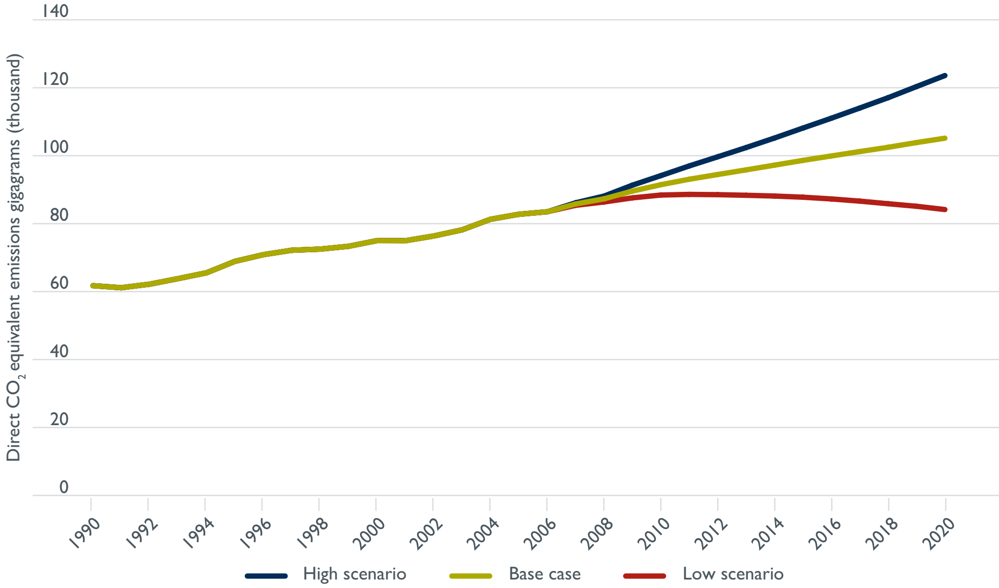
'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation). Biomass derived emissions are also not included (i.e. CO_2 emissions from the combustion of biofuels are excluded).

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

Sources: BTCE (1996a, 1996b, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Figure 4.6 High and low combination scenarios for total domestic transport emissions



Sources: BTCE (1996a, 1996b, 1995a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Chapter 5 Projection and estimation uncertainties

The sensitivity tests in the preceding chapter give some idea of the uncertainty associated with the projections, where even if the models are well formulated the difficulties inherent in accurately forecasting all the model input data and parameters mean that there will always be a certain range of fundamental variability in the results.

The sensitivity tests suggest this underlying variability of the projections to be of the order of a 5 per cent variation (in the projection period endpoint) for the sensitivity range in any one particular major parameter. Assuming the model structure is an accurate reflection of the transport sector's dynamics and that current travel behaviour trends continue, the results imply that 2020 aggregate emissions, in the absence of further abatement measures, are unlikely to lie more than 15–20 per cent from the base case values, unless there is major structural change to the sector (or there are other major unforeseen events impacting on transport activity, such as severe fuel shortages) before 2020. Of course, future Australian transport emissions could be significantly different from the levels projected here, depending on which greenhouse gas abatement policies are pursued (both domestically and internationally) over the coming years. For example, the establishment of the Australian Government's CPRS (along with any complementary measures also introduced) will doubtless have a range of impacts on transport choices.

Regarding structural change, there could be some projection uncertainty associated with the modelled saturation effects. The BITRE models have saturation constraints imposed on a variety of underlying transport trends (such as for future average per capita car travel). Deciding on the best value for such asymptotic saturation levels is often reasonably approximate, and partly dependent on the particular mathematical form chosen to fit or explain the trend data. Hypothetically, given the right conditions, even behavioural patterns currently following saturating or logistic trends could, in the future, leave such trend curves. That is, large enough economic changes, or technological innovations, could be capable of generating significant demand growth opportunities, perhaps such that the modelled saturation levels could then be exceeded within projection timeframes.

For example, very high fuel efficiency in future generations of hybrid motor vehicles (including plug-in hybrids, that can run for reasonable portions of their daily travel on battery power, or hydrogen fuel cell hybrids) could possibly offer such large reductions in motoring costs that substantial extra travel ('rebound' travel) is generated. Yet even if current technology bottlenecks could be overcome quite swiftly, and such highly efficient vehicles start being introduced in the near future, their overall penetration into the Australian vehicle fleet would probably still be relatively slight before 2020. Another hypothetical example of a structural change that could be significant enough (i.e. to have the capability of altering the shape of the expected saturation path) concerns the possible introduction, over the longer term, of driverless road vehicles. The availability of technology and infrastructure allowing autonomous vehicle movement will both increase the motorisation participation rate (with the possibility of vehicle use by persons currently too young to drive) and possibly support easier, more stress-free car trips. However, even though a substantial amount of computer-driven vehicle technology already exists at the prototype stage, deployment of such systems on actual roads is likely to be well into the future. The current base case assumption is that significant elements of driverless vehicle technology will not appear on our roads until well after the 2020 projection timeframe.

So, in summation, there is reasonable evidence that:

- certain saturating tendencies are historically robust (especially concerning per capita daily passenger travel, such as the trends plotted in Figures 3.1 and 2.3)
- many of the technologies with the possible capability of generating travel demand beyond the currently implied saturation levels are unlikely to be widely available before the 2020 projection endpoint
- such (saturation) asymptotes for per capita transport tasks are therefore legitimate parts of transport model configurations (at least for medium-term projections).

On the other hand, the medium-term BITRE freight modelling/projection processes (including results using BITRE's model of truck fleet dynamics, TRUCKMOD, and the components of the MVEm emission modelling suite that deal with rigid and articulated trucks) do not include any saturation constraints. It could be argued that (per capita) freight vehicle use may also face some saturation effects before 2020. However, as mentioned earlier, there is currently no evidence that Australian freight generation is levelling off yet, in any significant way. The base case projections are therefore done on the assumption that no saturation effects on per capita freight movement will occur before 2020. This is highly likely to be a sound approach over the medium term, but if projections had to be done over the longer term, say well beyond 2020, then freight saturation effects could also become important (where this topic is also the subject of ongoing BITRE research).

Regarding sudden events or other major contingencies affecting transport behaviour, the greatest uncertainty concerning the aggregate projection levels in Base Case 2007 probably remains the same as that for the previous few base cases, i.e. the risk of significant disruptions to oil supply occurring during the forecast period. Any extreme rises in automotive fuel prices will likely have severe impacts on transport activity levels, particularly for road and air travel.

The sensitivity analysis in the previous chapter addressed only a fairly moderate range in fuel price variations, with even the 'high' oil price scenario (chosen in early 2007) failing to cover the crude oil price levels actually encountered from about mid-2007 onwards. Extreme fuel price variations were not covered in this study, partly because very large increases in the price of crude oil will tend to be inflationary, and require modelling at a whole economy level, rather than just at the transport sector level (as for the current BITRE bottom-up modelling).

A related issue (to that of possible price spikes from short-term disruptions to oil production) is the timing of the possible 'rollover' in the global oil market (i.e. the point where the world demand for oil outstrips the market's capacity to supply that rate of petroleum production). There are still significant global oil reserves (especially if non-conventional sources such as tar sands and oil shales are included). However, with the steep projected growth in world future energy requirements, there is also a considerable amount of evidence to suggest that world oil demand is likely to overtake the economically viable level of total petroleum supply sometime this century. Even with the inclusion of less conventional sources (such as deep water oil production, tar sands and natural gas plant liquids)—i.e. at feasible rates of expansion, and assuming any environmental or technical problems hindering their greater use can eventually be circumvented—possible oil supply growth by mid-century is unlikely, according to some energy forecasters (e.g. BITRE forthcoming), to match expected demand growth. Further development of some non-conventional sources of oil could be affected by future climate change policies (e.g. the production of synthetic petroleum from bituminous sands tends to cause even higher CO_2 emissions, per unit of production, than for conventional crude oil, meaning policy measures, such as emission trading schemes, could have considerable price implications).

Even before there is major reserve depletion, oil prices will probably rise significantly, as the gap between global demand and the possible oil supply rate starts to widen. Once global depletion in conventional oil reserves eventually commences, fuel prices could rise dramatically, unless the projected gap between energy supply and demand can be bridged before then, either by increased energy efficiency or by the large-scale introduction of alternative fuels (such as hydrogen, new-generation biofuels, or derived/synthetic petroleum—e.g. coal-to-liquids, CTL—processes). Energy forecasters tend to disagree quite strongly about the timing of such a rollover or production peak, some predicting the short term, others predicting it to be well in the future. This debate is discussed in BTRE (2005a), and is being further investigated by ongoing BITRE research (BITRE forthcoming).

One of the highly quoted studies in this area has been published by the US Energy Information Administration (EIA), based on resource data compiled by the United States Geological Survey (USGS 2000). The results of EIA analyses (EIA 2000, 2004) are that the most likely timing of the global oil production peak (given current demand and recovery growth) will be between 2030 and 2040, and regarding the possible range they state:

> '… depending on what actually happens to demand, as well as on how fortunate the world eventually proves to be vis-a-vis the volume of its conventional crude oil resource endowment, peak world conventional crude oil production could plausibly occur anywhere between 2021 at a volume of 48.5 billion barrels per year and 2112 at a volume of 24.6 billion barrels per year, though neither of these extremes has a substantial probability of occurrence … [and] if the USGS mean resource estimate proves to be correct … world conventional crude oil production would be expected to peak in 2037 at a volume of 53.2 billion barrels per year.'

Even though the oil rollover point being reached is a possibility before 2020, the balance of current evidence suggests that significant gaps between oil supply and demand are more likely to occur over a longer timeframe and that the current projection scenarios should be approximately valid. However, any subsequent projection studies, attempting to forecast transport emissions well beyond 2020, will probably have to examine this issue further. Until future oil supply is more precisely known, fuel use projections longer than about a 2030 timeframe must be considered as highly uncertain.

As well as uncertainties about future oil availability, another (lesser) source of uncertainty in the 2020 projections relates to the projected magnitude of alternative fuel use by then, with the possibility either of existing alternative transport fuels gaining higher than foreseen market shares, or of new alternatives being successfully introduced (depending on the timing of technology breakthroughs and on the relative price incentives offered by more expensive crude oil). If use of such alternative fuels involves a substantially different carbon-intensity to petroleum then the greenhouse gas estimates would obviously be altered. BITRE Base Case 2007 projections contain a fairly strong growth rate for alternative fuel use in the road transport sector. However, even though alternative fuel use will probably account for significant proportions of vehicle energy consumption over the longer term, petroleum use is expected to remain dominant throughout the projection period to 2020. See Figure 5.1 for reference case estimates of fuel shares for projected car travel.

Given the relatively low use of alternative fuels at present (the use of LPG, natural gas and biofuels currently account for less than 6 per cent of total primary energy consumption by the domestic transport sector), market shares should remain relatively modest throughout the current forecast period (even with the generally strong expected growth rates). For example, referring to Appendix Table A21, under the base case scenario, the market shares of total road fuel sales for LPG, natural gas and biofuels are projected to reach respective levels of about 7.8, 0.4 and 0.9 per cent by 2020.

The medium-term aggregate projection levels are thus relatively insensitive to the scenario's assumptions concerning penetration of alternative fuels, not only due to their presently limited market shares, but also due to the current alternatives (primarily LPG, natural gas and grain-based ethanol) typically delivering only moderate environmental benefits. For example, if the 2020 market penetrations quoted above for these alternative fuels were doubled, it would make less than a 2 per cent reduction in the base case estimate of aggregate CO_2 emissions.

Large scale decreases in transport emissions from fuel switching will probably not occur until the full commercialisation of technologies that offer very low carbon intensities, such as:

- hydrogen sourced from renewable generation (like solar or wind power), used either in combustion engines or fuel cells
- the use of less carbon-intensive electricity provision (either from generation using a greater proportion of renewables or employing techniques such as carbon capture and sequestration) to power electric vehicles or 'plug-in' hybrids (i.e. petrol-electric hybrid vehicles with large storage batteries that can be recharged overnight at home)
- biofuels derived from lignocellulose (such as woody wastes) or bio-engineered algae.

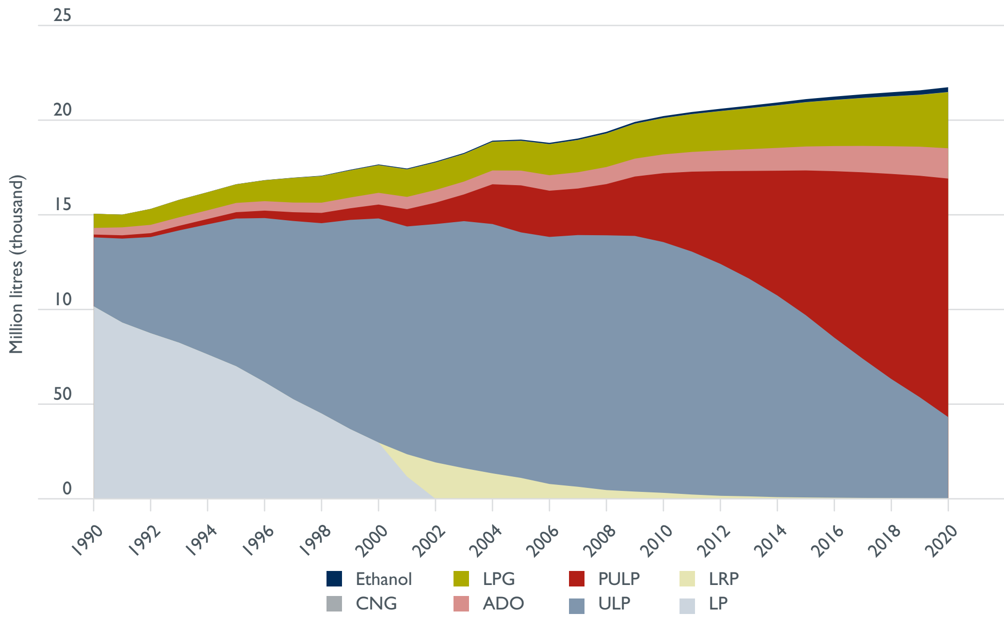
There is a wide range of energy sources that will probably eventually make significant contributions to the transport fuel mix, including:

- increased use of natural gas

- biofuels
- non-conventional petroleum—e.g. sourced from shale oils, or liquids converted from coal (CTL) or natural gas (GTL) using methods such as the Fischer-Tropsch (FT) Process—which could lead to increasing carbon intensity levels if not allied with CO_2 capture and storage during the processing
- successful commercialisation and use of new technologies such as hydrogen-fed fuel cells.

However, given the generally long lead times required for substantial mass-market penetration of new energy technologies, the significant levels of research and development still required for some alternatives, and that the price comparisons for many alternatives may not become attractive until after the conventional oil production peak, it is not very likely that more than a minor share of transport petroleum use will be substituted within the projection timeframe (of between now and 2020).

Figure 5.1 Projected fuel mix for Australian passenger cars to 2020



Notes: Ethanol is generally sold in a 10 per cent blend with automotive gasoline (petrol).
CNG—compressed natural gas (in litres of petrol equivalent, on an energy content basis)
LPG—liquefied petroleum gas
ADO—automotive diesel oil
PULP—premium unleaded petrol (including special proprietary brands)
ULP—unleaded petrol
LRP—lead replacement petrol (including all petrol altered by additives to combat valve seat recession)
LP—leaded petrol

Sources: BTRE (2006a, 2002a, 2003c) and BITRE estimates.

Since the preparation of the Base Case 2007 projections, changes to underlying parameters have included:

- historically high oil prices during 2008, and upward revisions to oil price forecasts by the major international energy agencies (such as the EIA and IEA).
- the Global Financial Crisis (GFC), also during 2008, with the consequent slowing in current economic growth rates—though with the general expectation that long-term economic growth will be largely unaffected.
- upward revision to ABS mid-range (series B) population projections (see ABS 2008). For some indication of the effects on the demand projections flowing from the higher population projections, see the BITRE-CSIRO appendix to the recent Treasury (2008) report on modelling climate change mitigation, (BITRE and CSIRO 2008) and a recent conference paper on the BITRE modelling (Cosgrove 2008). For an indication of the likely transport demand impacts of the economic slowdown, see a recent BITRE conference presentation (Cosgrove 2009). As mentioned previously, scenario analyses addressing high future oil prices are ongoing. The combined effects (on the overall projection levels) from these changes to potential parameter values, though likely to be significant over the longer term, will probably be relatively slight over the medium term (to 2020) addressed by this report.

Problems associated with estimating only direct emissions

The main emission projection values in this study (see Tables 1.1 and 1.2), in accordance with AGO specifications, include only *direct* CO_2 equivalent emissions, i.e. only the effects of the directly radiative gases emitted from transport fuel use: carbon dioxide, methane (CH_4) and nitrous oxide (N_2O). The AGO-specified Global Warming Potentials (GWPs) for calculating the CO_2 equivalent mass estimates for emissions of methane and nitrous oxide (21 times for CH_4 and 310 times for N_2O, using a reference period for warming effects of 100 years) are from previous IPCC (1996, 1997) guidelines on national greenhouse gas inventories that are currently used in Kyoto Protocol emission calculations. The most recent IPCC estimates of these GWP values (IPCC 2007a) are of similar magnitude (i.e. 25 times for CH_4 and 298 times for N_2O, over a 100 year reference period).

Due to the difficulty in accurately quantifying global averages for warming due to 'indirect' greenhouse effects (i.e. the effects of atmospherically short-lived gases such as carbon monoxide, which are not radiatively active themselves but which can influence the concentrations of the direct gases), IPCC (1996, 1997) reports used for the Kyoto Protocol factors did not give any GWP values for indirect greenhouse gases,[3] though estimates were provided of the total radiative forcing due to tropospheric ozone formed from such indirect gases. The standard (CO_2 equivalent) greenhouse gas emission estimates would be significantly higher if the indirect effects of other gases emitted from transport—particularly the ozone precursors

3. Note that an earlier IPCC (1990) report attempted to roughly quantify the indirect effects using a GWP approach, and more recent IPCC research reports (e.g. see IPCC 2001, http://www.grida.no/climate/ipcc_tar/wg1/249.htm) have also discussed ways to incorporate the indirect gases into a basic GWP reporting formulism. IPCC (2001) presents a possible carbon monoxide GWP of between 1 and 3.

such as carbon monoxide (CO), oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOCs)—were also taken into account.

AGO/DCC greenhouse gas inventories follow the UN Framework Convention on Climate Change (UNFCCC) reporting guidelines, which basically only require the inclusion of the direct greenhouse gases in aggregate CO_2 equivalent totals, though parties to the Convention are encouraged to also provide information on the emission volumes of carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), and sulphur oxides (SO_x), for input into detailed climate models. Note that this study gives emission time series and projections for these indirect gases in Appendix Tables A10 to A17. Estimates are also provided for particulate matter (PM) emissions from Australian transport (Appendix Tables A18 and A19), since not only do IPCC summaries of radiative forcing impacts include allowance for the considerable effects of black carbon deposition (e.g. IPCC 2007a), but recent research (Ramanathan et al. 2007) implies that the warming effects of soot emissions (particularly in the more-heavily populated regions of Asia) could be highly significant, and that control of fossil fuel particulate emissions may be one of the most effective methods of slowing global warming (Jacobson 2002).

Note that the overall climate effects of anthropogenic aerosols are complex, and difficult to estimate precisely, with the primary contributions of climate-influencing suspended particles from the transport sector being: the black carbon portion of vehicle particulate emissions—primarily from fuel combustion and tyre wear—which exert a net warming effect; and sulphates—formed in the atmosphere due to the sulphur component of particulate emissions and from SO_x emissions (especially from high-sulphur diesel or fuel oil combustion)—which tend to exert a net cooling effect. For aggregate transport sector emissions, it is likely that the net warming effects of black carbon outweigh the net cooling effects of the sulphates (e.g. see Figure 5.10), but this will vary by fuel and engine type.

GWP is not a concept used directly in climate modelling; it is a simplified metric, primarily introduced as a way of quickly weighting the climatic impact of emissions of different greenhouse gases and communicating the likely warming impact to policymakers. The limitations of the GWP formulation have lead to significant criticism in the literature but because of the simplicity of its application, the GWP has so far remained heavily in use (including within the Kyoto Protocol to the UNFCCC, where it is currently the specified method for defining national emission totals). There is considerable ongoing research into the design of alternative metrics (e.g. see Rypdal et al. 2005, Shine et al. 2005, and Fuglestvedt et al. 2001), which attempt to retain the transparency of the GWP concept, while aiming to better capture total radiative forcing effects (including the global impacts of the indirect greenhouse gases). Amongst other prominent researchers, Dr Jan Fuglestvedt (of Norway's Center for International Climate and Environmental Research), has argued that the use of non-optimal climate estimation metrics could possibly add to the cost of combating global warming, due to policymakers having difficulty in choosing the most worthwhile, or cost-effective, courses of action (for example, see UK Energy Research Centre 2004).

These issues should be borne in mind when assessments are being made with regard to emission abatement measures. Not only will calculated greenhouse gas emission levels be higher if future target negotiations manage to incorporate the indirect gases, but the scope for future abatement of those levels will also be widened (since pollutant control technology, or many other measures that promote the reduction of noxious non-CO_2 engine emissions, could also then be counted as greenhouse abatement measures).

In fact, care should be taken to not base the selection of the most effective abatement measures solely on their impacts with regard to the usual current definition of 'total' greenhouse gas emissions (i.e. direct CO_2 equivalent), since even though this is a comparatively sound indicator in many cases, it is capable of biasing assessments of some measures, especially if they mostly concern the output of non-CO_2 emissions.

For example, three-way catalytic converters are very efficient at reducing noxious emissions from road vehicles but their operation can lead to slight increases in N_2O emissions, a powerful direct greenhouse gas. So, despite their environmental and community health benefits, any policy sponsoring the increased penetration of such converters across the Australian vehicle fleet might receive a negative greenhouse assessment, if just direct CO_2 equivalent emissions were considered. However, a suitable quantification of the indirect greenhouse effects avoided by the converters' reduction of ozone-precursors is likely to be significantly greater than the possible slight increase in direct effects, probably making such a measure a particularly effective one, if assessed using changes in total radiative forcing.

This is likely to be the case with a variety of technologies that target overall levels of air pollution, as opposed to purely CO_2 emissions. Another example is suspended particle emissions and the more reactive of the volatile organic compounds (VOCs) released from transport fuel combustion. Most of the worst health effects due to urban air pollution originate from ultra-fine (respirable) particulates (which are not tightly controlled by current air quality or vehicle design standards, and are likely to remain at significant levels in our cities into the foreseeable future) and from carcinogenic VOCs such as benzene and poly-cyclic hydrocarbons (PAHs). Improved emission control systems on vehicles (and fuel reformulation at the refining stage) are typically capable of making major reductions in such pollutants—yet many of the most promising technologies have slight fuel efficiency overheads. That is, their use will tend to lead to a small increase in total fuel consumption, and thus a small increase in CO_2 emissions. However, in addition to the obvious social benefits of decreasing harmful air pollutant levels, this slight greenhouse 'negative' could possibly be cancelled out if the total (i.e. direct plus indirect) greenhouse emission changes from their use were considered, instead of solely changes to the direct gases.

Viewed in this light, even such current policy directions as pursuing the reduction of fuel sulphur content could be regarded more positively from a greenhouse abatement point-of-view (though this particular issue is complicated by the fact that sulphates due to vehicle emissions, which are harmful urban pollutants, probably cause a partial cooling effect). Not only does having ultra-low sulphur automotive fuels allow the introduction of new emission control technologies (which would otherwise have suffered rapid de-activation from sulphur-poisoning), but the lower sulphur content leads to longer average operational life-times for existing catalytic converters—serving to improve control of indirect greenhouse gas output from the vehicle fleet, and probably also reducing emission levels of the direct greenhouse gas N_2O (since its rate of emission has been strongly linked to catalyst deterioration). In fact, a number of international studies have shown that the reduction of fuel sulphur levels can lead to significant declines in N_2O emissions from motor vehicles (e.g. see USEPA 2004).

BTCE (1995a) and BTCE (1996a) attempted to roughly quantify a value for *total* CO_2 equivalent emissions from transport fuel combustion, calculated using six major gas species (CO_2, CH_4, N_2O, CO, NO_x and NMVOCs), generally producing emission aggregates approximately 20 per cent higher than those calculated using just the three direct gases (CO_2, CH_4, N_2O). Even though the short-lived gases are not well mixed in the atmosphere—and therefore do not lend themselves well to a global averaging process (such as attempted by the application of GWP values)—this study also endeavours to make allowance for the indirect effects of non-CO_2 transport emissions (see Table 5.1), rather than risk their consequences being ignored.

The emission totals given in the earlier sections of this report (i.e. in terms of direct CO_2 equivalent emissions from civil transport energy end use) are perfectly valid from an accounting point-of-view (as input to the sectoral components of a national emission total that satisfies current UNFCCC reporting guidelines). However, due to several factors that are excluded from these totals (e.g. indirectly radiative gas effects, upstream fuel processing emissions and international transport activity), they severely understate the actual greenhouse contribution of the whole transport sector. The rest of this chapter is devoted to deriving order-of-magnitude estimates that better reflect the total radiative forcing (i.e. overall warming effects) of Australian transport activity.

Indirect effects from non-CO_2 fuel combustion emissions

The BITRE base case estimates for *total* CO_2 equivalent emissions from civil domestic transport fuel use are given in Table 5.1 (and plotted in Figure 5.2). These values have been derived using a range of background material—such as current IPCC results for Radiative Forcing (RF) indices by different sources (IPCC 2007a, 2007b), earlier IPCC attempts to quantify GWPs for short-lived gas species (IPCC 2001, 1999, 1990), various papers on the derivation of GWP-like metrics (e.g. Fuglestvedt et al. 2001, Daniel & Solomon 1998, Fuglestvedt et al. 1996, Derwent et al. 2001, Johnson & Derwent 1996), and previous BITRE work in this area (e.g. BTCE 1996a, 1995a).

The estimates include a special allowance for the greater effect of aviation emissions that are released at high altitude, where the contribution of non-CO_2 indirect effects to aviation's total radiative forcing is considerable (see IPCC 1999). The literature appears to roughly concur that adding indirect effects (especially of high altitude ozone and contrails) gives a total RF value for aviation roughly double that of the direct CO_2 emissions alone; and, even though this value is, as yet, still highly uncertain, that it is most likely to lie somewhere between 1.5 times and 4 times the CO_2 total (Jardine 2005, Fuglestvedt et al. 2001). Forster et al. (2006) have modelled effective GWP values for separate components of aviation emissions, and derived a current 'best' estimate for an Emission-Weighting Factor (EWF) for total aviation warming effects—over a standard time horizon of 100 years—of 1.7 times the forcing due to fuel combustion CO_2 alone. The GWP-metrics applied to non-CO_2 aviation emissions, in the current BITRE analyses, have been estimated using the Forster et al. (2006) EWF result.

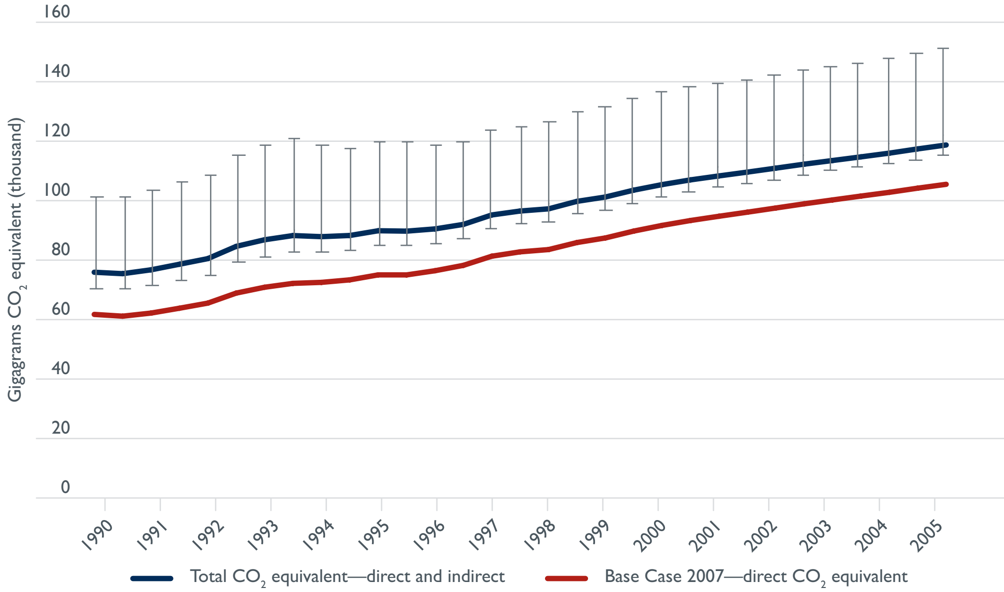
As demonstrated by the Table 5.1 results, including the indirect warming effects (evaluated over the standard 100 year time horizon) are estimated to increase the direct CO_2 equivalent values for Australian domestic transport by around 23 per cent for 1990; add about 16 per cent to current direct forcing totals; and are projected to contribute something like an additional 13 per cent to the direct gases' warming potential in 2020. These total CO_2 equivalent emission results use UNFCCC values for direct GWP values, to cover emissions of CO_2, CH_4 and N_2O, and BITRE estimates of possible indirect GWP values, for emissions of CO, NO_x and NMVOCs. No fully satisfactory GWP-like values appear to have yet been derived for black carbon or sulphur aerosols—so their effects are not included in the quantities provided in Table 5.1 and Figure 5.2—but the possible relative magnitude of their net radiative effect is roughly illustrated in Figure 5.10 (using the results of studies such as Reddy and Boucher 2007 and Jacobson 2002).

Due to the difficulty in evaluating such indirect effects, these total CO_2 equivalent figures have a relatively high uncertainty and are presented as ballpark estimates, to help give some idea of the likely magnitude of the non-CO_2 effects that are often left out of greenhouse abatement discussions (essentially due to the current lack of indirect GWP-like metrics applied within agreements such as the Kyoto Protocol). As well as the underlying uncertainty in such GWP-like multipliers, the current BITRE 'central' estimates (given in Table 5.1 and plotted in Figure 5.2) are generally made on the side of caution, i.e. are based on relatively conservative values for the chosen RF metrics (and are 'central' in the sense of lying close to the current *most generally accepted* values amongst the literature's range, rather than lying directly in the middle of a numerical span across those literature values).

For example, literature results of a globally averaged warming potential for CO emissions vary between a value of slightly above 1 times to values greater than 7 times that for CO_2, while the BITRE estimates are made using the assumption that if the CO emissions occur in urban areas conducive to ozone-formation that a value of 3 times applies but that most non-urban emissions will not tend to result in significant ozone concentrations; yielding a national average estimate for carbon monoxide's effective GWP of about 1.7 times CO_2, well below a simple median value, of about 4, across the literature value range.

Figure 5.2 uses 'error' bars on the central estimates' trend line to give an indication of the likely range for domestic transport's indirect warming contribution (given the current understanding of such indirect effects). Note that the central trend line for these total CO_2 equivalent values lies appreciably closer to the lower bound of the estimated range than to the upper bound, displaying the generally conservative nature of the indirect warming evaluation (used for Tables 5.1 and 5.2, and for Figures 5.6 to 5.10).

Figure 5.2 Comparison of trend in direct CO_2 equivalent emissions from civil domestic transport with estimated total emission levels, 1990–2020



Notes: The total CO_2 equivalent values given are a 'central estimate' for the total warming effects of fuel combustion by Australian civil domestic transport (including both direct and indirect radiative forcing, from the six gas species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs). The indirect effects of particulate and SO_x emissions from transport are not included.

Emissions include net biomass emissions (i.e. do not include CO_2 released from the in-vehicle combustion of biofuels, but do include emissions due to biofuel production). Totals are otherwise energy end use emissions, i.e. do not include other upstream fuel supply and processing emissions (such as from power generation for electric railways, or from petrol refining).

Error/uncertainty bars on total trend give likely upper and lower bounds for the estimated aggregate effects of including the radiative forcing due to indirect greenhouse gases.

Sources: BTE (1999a), BTCE (1995a, 1996a), BTRE (2002a, 2003a, 2003c, 2006a), Forster et al. (2006), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1999, 2001, 2007a) and BITRE estimates.

Table 5.1 Projections of greenhouse gas emissions from Australian civil domestic transport to 2020, fuel combustion, including indirect effects

Financial year	*BITRE Base Case 2007 direct emission projections (including net biomass)*	*Projected energy end use greenhouse emissions adjusted to include indirect warming effects of non-CO_2 emissions*
	(gigagrams of CO_2 equivalent)	
1990	61 743	75 927
1991	61 149	75 444
1992	62 192	76 741
1993	63 826	78 616
1994	65 540	80 505
1995	68 913	84 628
1996	70 883	86 851
1997	72 188	88 264
1998	72 522	87 894
1999	73 364	88 288
2000	75 039	89 883
2001	75 033	89 751
2002	76 433	90 503
2003	78 247	92 017
2004	81 321	95 199
2005	82 790	96 519
2006	83 553	97 251
2007	85 918	99 775
Forecasts		
2008	87 461	101 231
2009	89 776	103 543
2010	91 688	105 412
2011	93 334	107 000
2012	94 757	108 328
2013	96 131	109 609
2014	97 532	110 937
2015	98 942	112 279
2016	100 249	113 509
2017	101 548	114 735
2018	102 811	115 989
2019	104 212	117 414
2020	105 502	118 729

Notes: The total CO_2 equivalent values given are a 'central estimate' for the total warming effects of Australian civil domestic transport (including both direct and indirect radiative forcing, from the six gas species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs). See Figure 5.2 for an indication of the uncertainty levels in this estimation process.

Since the net climatic consequences of aerosols are not yet fully quantified, the effects of particulate and SO_x emissions from transport are not included in the table values. See Figure 5.10 for a rough indication of the likely magnitude of net warming due to vehicle emissions of black carbon and sulphates.

Emissions here include net biomass emissions (i.e. do not include CO_2 released from the in-vehicle combustion of biofuels, but do include emissions due to biofuel production). Totals are otherwise energy end use emissions, i.e. do not include other upstream fuel supply and processing emissions (such as from power generation for electric railways, or from petrol refining).

For converting into CO_2 equivalent figures, emission volumes of direct greenhouse gases use Global Warming Potential (GWP) values of carbon dioxide = 1, methane = 21 and nitrous oxide = 310. For indirect effects, it is assumed that emissions of the ozone precursors (carbon monoxide, nitrogen dioxide and volatile organic compounds) only attain a significant warming potential if emitted in urban areas (with GWPs then averaging approximately 3, 8 and 6 respectively), or at altitude (effective GWP for aviation NO_x emissions then around 150).

Sources: BTE (1999a), BTCE (1995a, 1996a), BTRE (2002a, 2003a, 2003c, 2006a), Forster et al. (2006), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1999, 2001, 2007a) and BITRE estimates.

Full fuel cycle emissions

In addition to the inclusion of indirect warming effects, a more robust estimate for the total contribution (to global climate change) of Australian transport should also allow for 'full fuel cycle' (FFC) emissions from transport vehicle energy use. That is, sector totals will be even higher if emissions released during transport fuel supply and processing are included as well as those from the direct fuel combustion. FFC estimates include energy use and emissions due to fuel extraction, power generation (e.g. for electric railways, see Table 2.3 for direct CO_2 equivalent estimates) and fuel refining or conversion. FFC estimates in previous BITRE studies have typically added between 10 to 20 per cent to energy end use emission totals for transport (BTRE 2006a, BTRE 2002a, BTCE 1995a).

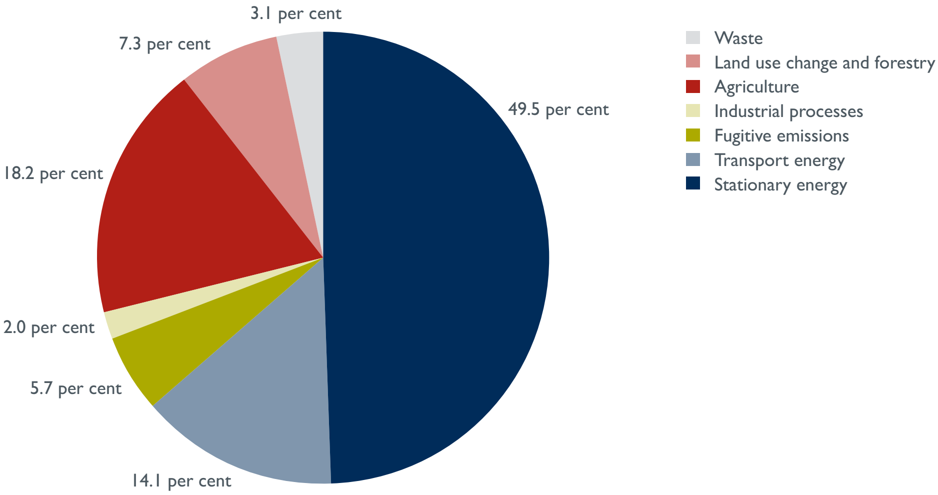
Note that Australia's NGGI reports greenhouse gas emissions using standard IPCC allocation sectors: *Energy* (including all stationary power generation, as well as transport fuel combustion); *Industrial processes*; *Solvents*; *Agriculture*; *Land use change and forestry*; and *Waste* (for further details, see the Department of Climate Change's website, at http://www.climatechange.gov.au/inventory/).

This 'accounting' structure, which is also used when reporting emission totals under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, is fully appropriate for the compilation of emission inventories (e.g. it helps reduce double-counting when a particular economic activity generates emissions across several different physical areas). However, such 'Kyoto-accounting' frameworks were not developed for the purpose of enabling emissions to be directly linked with their relevant economic activities, and hence are often less useful when comparing sectoral emission levels, and for assessing possible emission abatement policies (applied to particular activity sectors). For example, emissions from electricity generation (the largest single component of the NGGI) are completely attributed to the 'Energy Industries' subsector and not to the manufacturing, commercial or residential end use sectors which actually consume most of that electricity. From a transport sector perspective, some emissions actually produced because of transport activities—such as emissions from refining the petrol consumed by motor vehicles, or from generating power for electric railways—are allocated to stationary energy transformation.

To help understand the full contribution of different end use sectors to national CO_2 equivalent totals, and to assist in the development and tracking of greenhouse gas reduction measures, the AGO commissioned a re-allocation analysis of the sectoral levels within the NGGI, which covered the 1990, 1995 and 1999 inventories (AGO 2002). This end use re-allocation study involved integrating the energy and the non-energy emissions related to each major economic activity, and combining each sector's direct fuel combustion emissions with the relevant fugitive releases and upstream combustion emissions (i.e. those associated with energy production, refining and supply). The essential result of this analysis was FFC emission estimates for each of the major end use categories in the Australian economy—according to Australian and New Zealand Standard Industrial Classification (ANZSIC) divisions—for the 1990, 1995 and 1999 inventory years.

The variations that re-allocation makes to the various sectoral emission estimates are displayed in the following three charts. Figure 5.3 presents the composition of net Australian greenhouse gas emissions (domestic, direct CO_2 equivalent) using the sectoral divisions straight out of the NGGI methodology (i.e. according to IPCC allocation sectors).

Figure 5.3 Australia's National Greenhouse Gas Inventory for 1999, IPCC allocation sectors



Notes: The 'stationary energy' sector includes all fuel combustion activities related to electricity generation, independent of which end use sector actually consumes the electricity.

Emissions are direct greenhouse gas emissions only – carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide). Note that releases of some halocarbons are estimated by the National Inventory, but that chlorofluorocarbon (CFC) emissions are not included in the NGGI.

National net (domestic) emissions in the 1999 NGGI are 524 million tonnes of CO_2 equivalent (of which energy use accounted for around 364 million tonnes).

Source: AGO (2002).

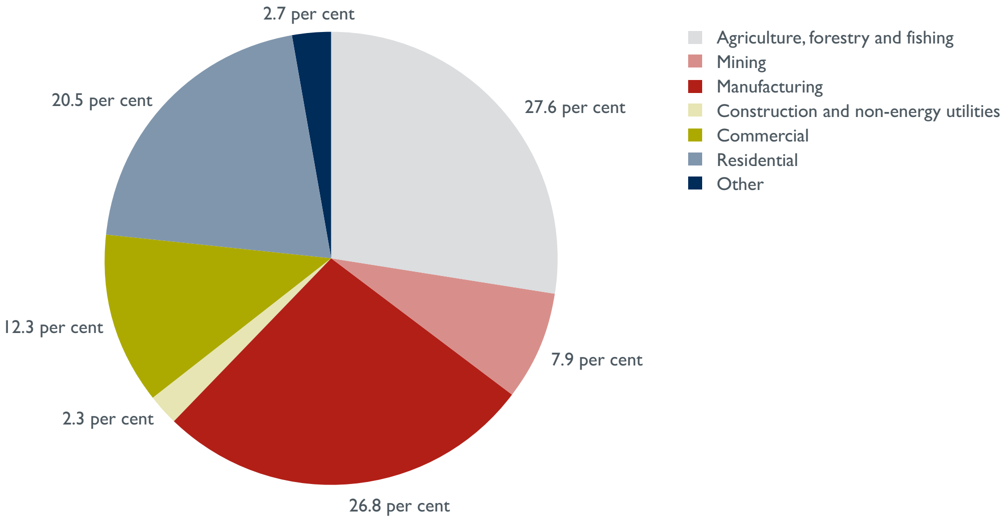
The primary analysis of AGO (2002) treated transport as a derived demand, i.e. rather than dealing with transport as an end use sector in its own right, most transport activities were assigned to the sector of the economy (*agriculture, forestry and fishing*; *mining*; *manufacturing*; *construction and non-energy utilities*; *commercial*; or *residential*) that the travel or freight activity served. For example, freight transport emissions were roughly allocated to the various end use sectors according to the type of commodity being carried.

While total emissions in Figure 5.3 were dominated by the share of stationary energy transformation (mostly due to electricity generation), the re-allocation to end use sectors (shown in Figure 5.4) highlights the prominence of the contributions due to the primary industries (mainly agriculture and mining) and to manufacturing, with the residential sector also having a significant share. The subdivision method of Figure 5.4 generally allows for more meaningful comparisons to be made between sectoral emission totals, than is possible simply using the inventory accounting segmentation (Figure 5.3).

Figure 5.5 separates out the transport sector from Figure 5.4's end use categories, since from a perspective of wanting to assess transport-related measures, it is generally more useful to not fully disaggregate emissions due to transport activities across the other sectors. The transport sector share presented in Figure 5.5 thus relates to full fuel cycle emissions, i.e. includes not only fuel combustion by vehicles, but also 'upstream' emissions from energy supply (primarily from petrol refining and electricity generation for railways).

Figure 5.4 presents the results of re-allocating the 1999 NGGI sectoral values into the economic end use sectors.

Figure 5.4 Australia's National Greenhouse Gas Inventory for 1999, end use sector allocation, disaggregating transport



Notes: 'Other' includes military fuel use, along with any unallocated transport, land-use change or solvent use.

As a simplifying assumption, all car travel to and from work and for private purposes has been allocated to 'residential', and all car travel for business purposes has been allocated to 'commercial'.

Emissions are direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide). Note that releases of some halocarbons are estimated in the NGGI, but that chlorofluorocarbon (CFC) emissions are not currently included in the NGGI.

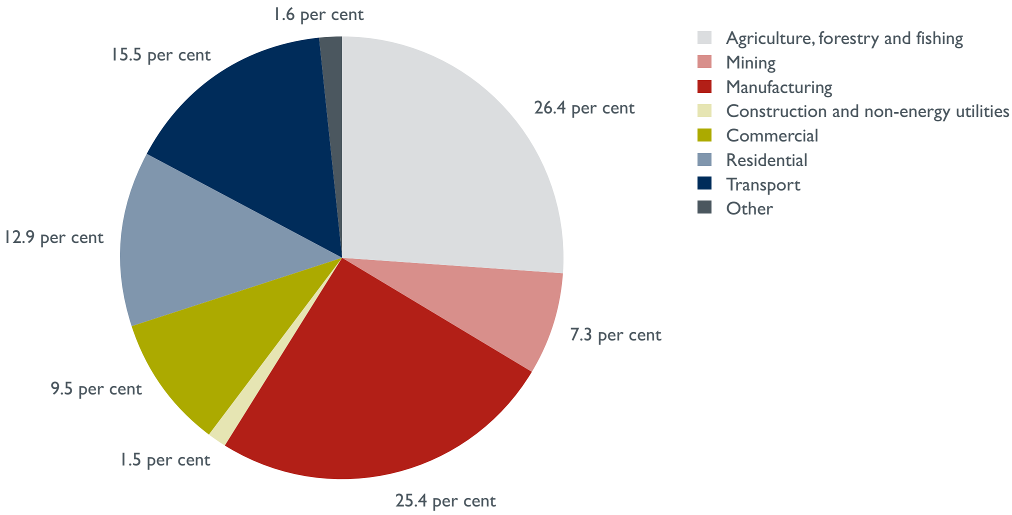
National net (domestic) emissions in the 1999 NGGI are 524 million tonnes of CO_2 equivalent (of which energy use accounted for around 364 million tonnes).

Source: BITRE estimates based on AGO (2002).

Referring to Figure 5.5, the domestic transport sector (on a FFC basis) has a significant share of national net emissions (at about 15.5 per cent of direct CO_2 equivalent), with a similar order of magnitude to that of the 'residential' end use sector (which has a smaller share in Figure 5.5's segmentation than in the previous graph, due to Figure 5.4's residential value also including emissions from private passenger travel), but below that of the two largest contributors, the agriculture, fishing and forestry sector and the manufacturing sector. Note that, unlike transport, end use emission totals for the agricultural sector are primarily non-energy in nature (e.g. from livestock and soil releases, and from deforestation). The shares in Figures 5.4 and 5.5 for 'agriculture, fishing and forestry' are substantially larger than the 'agriculture' sector share in

Figure 5.3, mainly due to the re-allocation of most 'Land use change and forestry' emissions in the NGGI to this end use sector.

Figure 5.5 Australia's National Greenhouse Gas Inventory for 1999, end use sector allocation



Notes: 'Other' includes military fuel use, along with any unallocated land-use change or solvent use.

Emissions are direct greenhouse gas emissions only – carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide). Note that releases of some halocarbons are estimated by the National Inventory, but that chlorofluorocarbon (CFC) emissions are not included in the NGGI.

National net (domestic) emissions in the 1999 NGGI are 524 million tonnes of CO_2 equivalent (of which energy use accounted for around 364 million tonnes).

Source: BITRE estimates based on AGO (2002).

The rest of the charts in this chapter include allowances for the full fuel cycle when illustrating trends in transport sector emission totals.

Table 5.2 gives the BITRE estimates of total CO_2 equivalent emissions (direct and indirect effects) from the full fuel cycle for Australian civil domestic transport, where the FFC values are, on average, about 13–14 per cent higher than the end use totals (given in Table 5.1). Using these more complete valuations of civil domestic transport's aggregate warming potential gives an estimate for total FFC emissions over 2007 of 113.2 million tonnes (total CO_2 equivalent), approximately 32 per cent higher than the Kyoto-accounting value for this year (85.8 million tonnes of direct CO_2 equivalent from energy end use). For 2020, the difference is about 29 per cent, with the projected FFC value for total CO_2 equivalent of 135.3 million tonnes, compared with 105.2 million tonnes projected for direct CO_2 equivalent from domestic transport energy end use.

As well as these additions (for indirect warming effects and upstream energy processing) to the direct CO_2 equivalent values for domestic energy end use, emission totals for the transport sector would be even more comprehensive if they included:

- a proportion of the emissions due to international transport to and from Australia

- related emissions from additional sources, such as military transport or energy use for commodity movements by pipelines (where Australian military fuels plus the energy consumption to operate major oil and gas pipelines probably account for a further 2–4 per cent of aggregate transport emissions)
- any of a wide range of additional life cycle emissions, from sources associated with transport vehicle use and transport infrastructure provision (e.g. emissions from energy used in vehicle construction, repairs and disposal; evaporative losses from service stations; road and rail-track construction, maintenance and signal operation; energy consumption due to railway stations and airports). BITRE estimates of the emission add-on for such full system cycle effects are in the order of a further 15 per cent (BTCE 1995a).

Choosing the most reasonable method for allocating international transport emissions between the various countries involved in international trade is a very controversial and complicated question, which has already been at the centre of many policy debates (for some background to this issue see Faber et al. 2007, *Aviation and maritime transport in a post 2012 climate policy regime*).

The current targets under the Kyoto Protocol do not cover international transport emissions, and existing NGGI guidelines do not require the inclusion of emissions from fuel use by international vessels or aircraft within the national CO_2 equivalent totals, though emissions from those international craft consuming fuel purchased in Australia are reported separately to the national domestic totals (see Tables 2.5 and 2.8 for BITRE time series estimates and projections of this component of total international fuel use).

This standard jurisdictional allocation used currently for international transport (i.e. based on the amount of fuel uplifted or bought within the country) probably serves to understate a properly equitable share of Australian emissions, since the bulk of fuel consumed by international shipping involved in Australian trade is bought overseas. On the other hand, allocating *all* fuel used by international craft both into and out of Australia (see Tables 2.4 and 2.7 for consumption estimates) would grossly exaggerate a suitable national allocation. As an indicative estimate of the relative importance of international transport's contribution to aggregate sector totals (i.e. for demonstration purposes, and not necessarily suggested as a suitable allocation mechanism), Table 5.2 also gives FFC estimates that include half of the emissions due to total fuel use by international shipping and aviation travelling to and from Australia. This will still tend to overstate Australia's share of international transport emissions (since a proportion of international travel will involve several ports-of-call during the full voyage), but should be closer to a balanced allocation than purely country of fuel uplift.

Referring to Table 5.2, the BITRE base case estimates of total CO_2 equivalent emissions (direct and indirect effects) for Australian transport sector fuel use (civil transport energy use on a full fuel cycle basis, including the international transport allocation) are approximately 149 million tonnes for 2007, around 74 per cent higher than the domestic end use totals given in Table 5.1, and are projected to grow to around 185.5 million tonnes by 2020 (76 per cent higher than the 2020 domestic energy end use estimates). These calculations are done on the assumption that the indirect GWP unit values derived for the domestic aviation estimates are also valid for international aviation.

Table 5.2 Projections of greenhouse gas emissions from Australian civil transport to 2020, including the full fuel cycle

Financial year	*Domestic transport*	*Total transport sector (including half of estimated fuel use due to international craft visiting Australia)*
	(gigagrams of CO_2 equivalent)	
1990	85 682	108 900
1991	85 103	110 051
1992	86 562	112 796
1993	88 618	116 032
1994	90 723	119 398
1995	95 410	126 753
1996	97 838	129 416
1997	99 535	132 727
1998	99 189	132 217
1999	99 713	132 317
2000	101 611	135 302
2001	101 501	135 347
2002	102 430	133 395
2003	104 185	134 514
2004	107 797	140 171
2005	109 346	144 966
2006	110 275	145 712
2007	113 166	148 992
Forecasts		
2008	114 876	151 928
2009	117 531	155 890
2010	119 690	15 9522
2011	121 531	162 700
2012	123 089	165 120
2013	124 598	167 532
2014	126 157	170 258
2015	127 731	172 890
2016	129 182	175 402
2017	130 629	177 831
2018	132 098	180 235
2019	133 759	182 885
2020	135 300	185 469

Notes: The total CO_2 equivalent values given are a 'central estimate' for the total warming effects of Australian civil transport fuel use (including both direct and indirect radiative forcing, from the six gas species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs). The indirect effects of particulate and SO_x emissions from transport are not included.

Emissions here include net biomass emissions (i.e. do not include CO_2 released from the in-vehicle combustion of biofuels, but do include emissions due to biofuel production) and full fuel cycle (FFC) emissions, i.e. include upstream fuel supply and processing emissions (such as from power generation for electric railways).

For converting into CO_2 equivalent figures, emission volumes of direct greenhouse gases use Global Warming Potential (GWP) values of carbon dioxide = 1, methane = 21 and nitrous oxide = 310. For indirect effects, it is assumed that emissions of the ozone precursors (carbon monoxide, nitrogen dioxide and volatile organic compounds) only attain a significant warming potential if emitted in urban areas (with GWPs then averaging approximately 3, 8 and 6 respectively), or at altitude (effective GWP for aviation NO_x emissions then around 150).

Sources: BTCE (1995a, 1996a), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), Forster et al. (2006), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1991, 2001, 2007a) and BITRE estimates.

The separate modal contributions to full fuel cycle estimates (of total sectoral emissions across all major transport utilisation) are displayed in Figure 5.6 for domestic civil transport and in Figure 5.7 for total transport to, from and within Australia (based on the aggregate values given in Table 5.2, where modal time series are provided in Appendix Tables A30 to A32).

Total greenhouse gas emissions from transport

The estimates in Table 5.2, and Figures 5.6 and 5.7, present a comprehensive accounting of the majority of greenhouse gas emissions due to energy use by Australian transport. As discussed previously, the net climatic effects of transport-related aerosols (such as black carbon from particulate emissions and sulphates from SO_x emissions) are not included in these values and their inclusion would probably contribute some additional radiative forcing (see Figure 5.10 for a rough estimation of the possible scale of the net warming contribution due to vehicle emissions of black carbon and sulphates).

Yet, even with a full accounting of the radiative contribution due to transport fuel use, there remains one major source of transport-related greenhouse gas emissions still to be considered: halocarbon releases from motor vehicle airconditioning systems and from refrigerated transport. Vehicle airconditioning emissions form one of the main components of the 'Industrial processes' sector within the NGGI—and similarly to the previous section, which re-allocated stationary energy emissions to appropriate end uses, this section presents estimates of aggregate transport emissions after re-allocating the halocarbon emissions due to transport activities.

Previous BITRE studies have attempted to include transport-related halocarbon emissions in aggregate sectoral (CO_2 equivalent) estimates—e.g. see, for example, BTCE (1995a, Chapter 1)—but the accuracy of these initial calculations was limited by a lack of data on halocarbon release rates. A suitable quantification of such fugitive releases from transport vehicle air conditioners is now possible due to another detailed study commissioned by the AGO: *Inventories and Projections of Ozone Depleting and Synthetic Greenhouse Gases used in Montreal Protocol Industries* (Burnbank Consulting 2002), which estimates time series, by industry, for releases of synthetic gases, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, methyl bromide, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Halocarbon emissions from motor vehicle airconditioning systems arise from the initial charging of the units with refrigerant, leakage of the refrigerant during operation, losses during servicing or system replacement, and venting on vehicle or system disposal. Until 1994, airconditioning units used in Australian motor vehicles were primarily charged with the ozone-depleting chloroflurocarbon CFC-12 and since chlorofluorocarbons also happen to be very potent greenhouse gases, CFC leakage was one of the largest contributors to aggregate greenhouse gas emissions from Australian transport throughout the 1980s and 1990s.

Since the gradual phase out of CFC production from 1995 onwards (under the provisions of the *Montreal Protocol on Substances that Deplete the Ozone Layer*), use of the synthetic gas HFC-134a has grown rapidly. Not only were most new vehicle airconditioners then charged with HFC-134a, but subsequent retrofits of systems on older vehicles also typically used HFC-134a. Replacement refrigerant gases such as HFC-134a are substantially less (stratospheric) ozone-depleting than CFCs but are still generally quite strong greenhouse gases.[4] The average 100 year GWP of HFC-134a is around 1400 (i.e. relative to CO_2). This is considerably less than that of CFC-12 (at around 10 000 times CO_2)—so total CO_2 equivalent emissions from domestic transport could have actually fallen for a few years in the late 1990s—but still large enough that halocarbon release is likely to remain a significant source of radiative forcing over at least the medium term (see Figure 5.8).

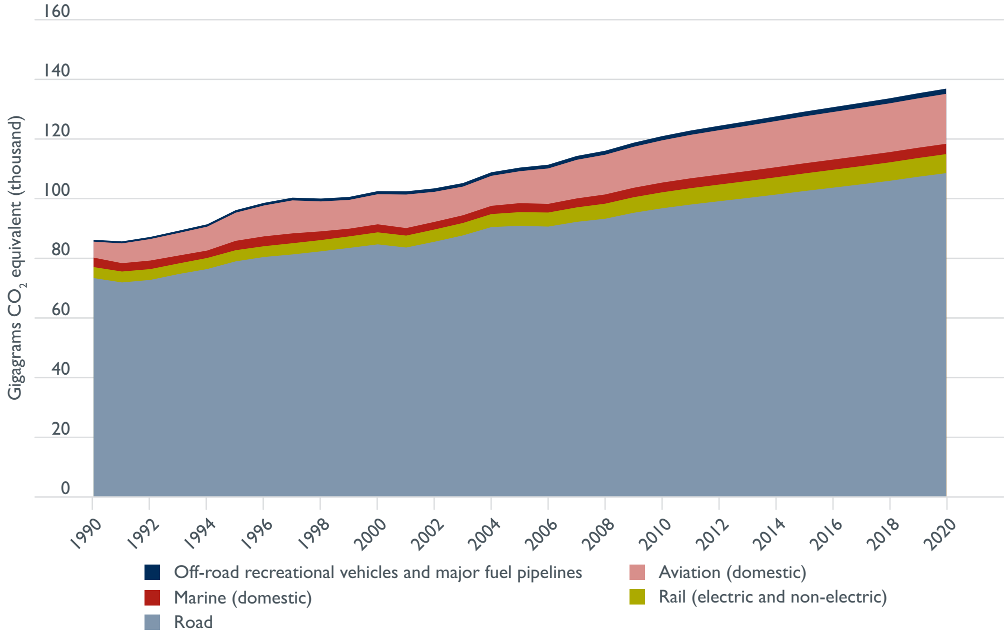
The AGO-commissioned report into synthetic gas releases (Burnbank Consulting 2002) also remarks that some of the options for limiting future emissions from motor vehicle air-conditioning are relatively simple and should not require any new technology development. Significant reductions should be possible by tightening industry management practices, supporting the greater incidence of refrigerant recycling when systems are serviced, and higher rates of halocarbon recovery when vehicles are scrapped.

Figure 5.9 displays the differences between the estimated emission levels obtained for civil domestic transport, depending on whether the calculations:

1. include purely the effects of the directly radiative gases CO_2, CH_4 and N_2O, released from fuel combustion in transport vehicles (i.e. standard inventory, or 'Kyoto-accounting' CO_2 equivalent values for the transport sector)
2. additionally, allow for the effects of the indirectly radiative gases CO, NO_x and NMVOCs due to transport vehicle use, and for any extra greenhouse emissions generated over the FFC (upstream energy supply, processing and transformation emissions)—giving total CO_2 equivalent emissions from domestic transport energy use, or
3. furthermore, allow for the direct warming effects of fugitive halocarbon releases (primarily HFCs, HCFCs and CFCs) from Australian motor vehicle air-conditioning systems and refrigerated transport vehicles—giving total CO_2 equivalent emissions from domestic transport activity.

4. Note that releases of synthetic gases such as HFCs and PFCs are included in the current NGGI, but that emissions of CFCs are not—since the NGGI methodology assumes that control and monitoring of ozone-depleting gases is adequately handled by processes under the Montreal Protocol. Currently, there would still be some emissions of CFCs from older vehicles, but annual levels would now be relatively small, and should fall practically to zero within the next few years or so.

Figure 5.6 Modal composition of full fuel cycle emissions from the civil domestic transport sector, Australia, total CO_2 equivalent, 1990–2020

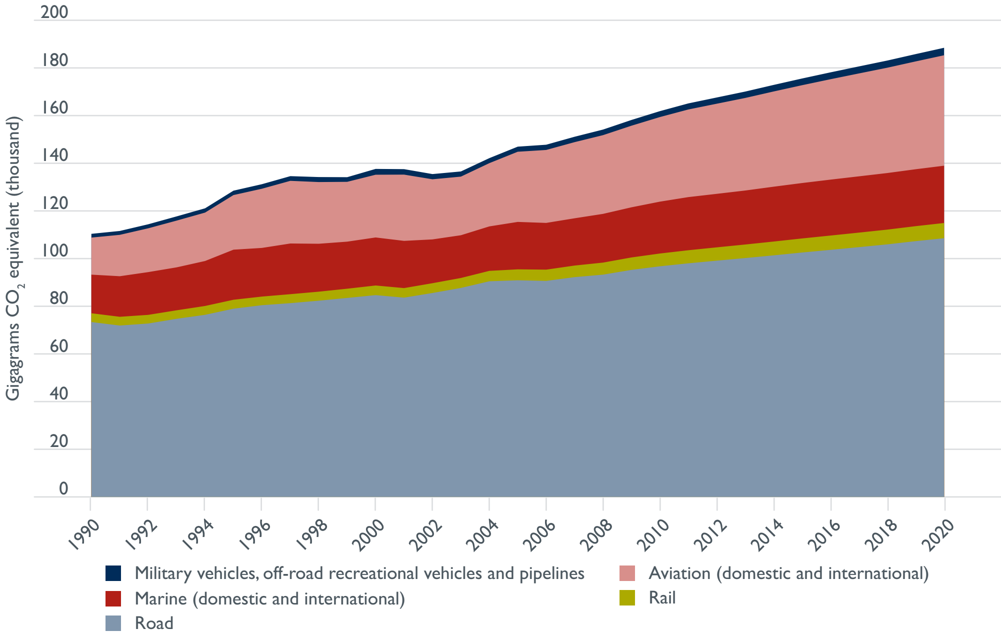


Notes: The modal shares sum to an estimate of total CO_2 equivalent (both direct and indirect) for the full fuel cycle emissions of the domestic transport sector—covering all civil transport within Australian (including energy use by major oil and gas pipelines).

The total CO_2 equivalent values given are a 'central estimate' for the total warming effects of Australian civil domestic transport fuel use (including both direct and indirect radiative forcing, from the six gas species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs). The indirect effects of particulate and SO_x emissions from transport are not included.

Sources: BTCE (1995a, 1996a), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1991, 2001, 2007a) and BITRE estimates.

Figure 5.7 Modal composition of full fuel cycle emissions from the Australian transport sector, total CO_2 equivalent, 1990–2020

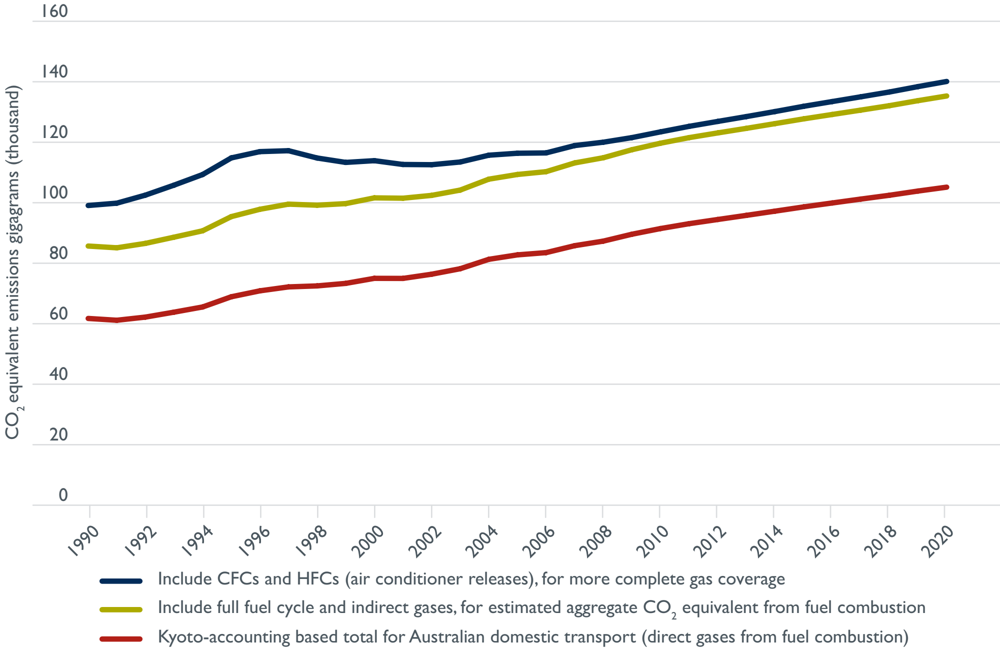


Notes: The modal shares sum to an estimate of total CO_2 equivalent emissions (both direct and indirect), for the full fuel cycle emissions of the Australian transport sector —and include all civil domestic transport, and half the fuel used by international transport to and from Australia; as well as Australian military fuel use, and energy use by major oil and gas pipelines.

The total CO_2 equivalent values given are a 'central estimate' for the total warming effects of Australian civil transport fuel use (including both direct and indirect radiative forcing, from the six gas species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs). The indirect effects of particulate and SO_x emissions from transport are not included.

Sources: BTCE (1995a, 1996a), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1991, 2001, 2007a) and BITRE estimates.

Figure 5.8 Contribution of halocarbon releases from motor vehicle air conditioners to aggregate domestic transport emissions



Notes: Kyoto-accounting CO_2 equivalent values (lower trend line) are an estimate for the *direct* warming effects of Australian civil domestic transport energy end-use, from the three gas species CO_2, CH_4 and N_2O.

The middle line gives rough estimates of the total warming effects of Australian civil domestic transport fuel use (in total CO_2 equivalent values, including both direct and indirect radiative forcing), from the six gas species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs.

The uppermost trend values also include the direct warming effects of halocarbon refrigerant releases (primarily HFCs, HCFCs and CFCs) from Australian transport vehicles.

The indirect climatic effects of particulate and SO_x emissions from transport are not included here (see figure 5.10).

Sources: BTCE (1995a, 1996a), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), Burnbank Consulting (2002), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1999, 2001, 2007a) and BITRE estimates.

Figure 5.9 goes on to compare several of the expanded trends discussed in this chapter (where emissions associated with transport activities, but usually assigned to other sectors of the national inventory—or not previously well quantified—have been re-allocated to the transport sector) with the standard inventory-based trend (see Table 1.2 for the Base Case 2007 values). Starting with the transport values as calculated according to current NGGI guidelines (i.e. direct CO_2 equivalent emissions from domestic energy end use)—displayed at the base of the trend lines in Figure 5.9—the estimated effects of the indirect gases are first added, then a more comprehensive trend line, for domestic transport energy use, is obtained by adding in the full fuel cycle effects. From these domestic values, indicative estimates for total Australian transport energy use are then obtained by adding an allowance for emissions from international aviation and shipping to and from Australia.

The upper two trend lines shown in Figure 5.9 are then obtained by adding:

a. rough allowances for military fuel use, for energy use by major oil and gas pipelines, and for other 'full system cycle' effects—i.e. extra emissions caused by transport vehicle manufacture and disposal, and due to transport infrastructure construction, maintenance and operation—and

b. likely direct radiative effects of halocarbon refrigerant releases from Australian transport vehicles.

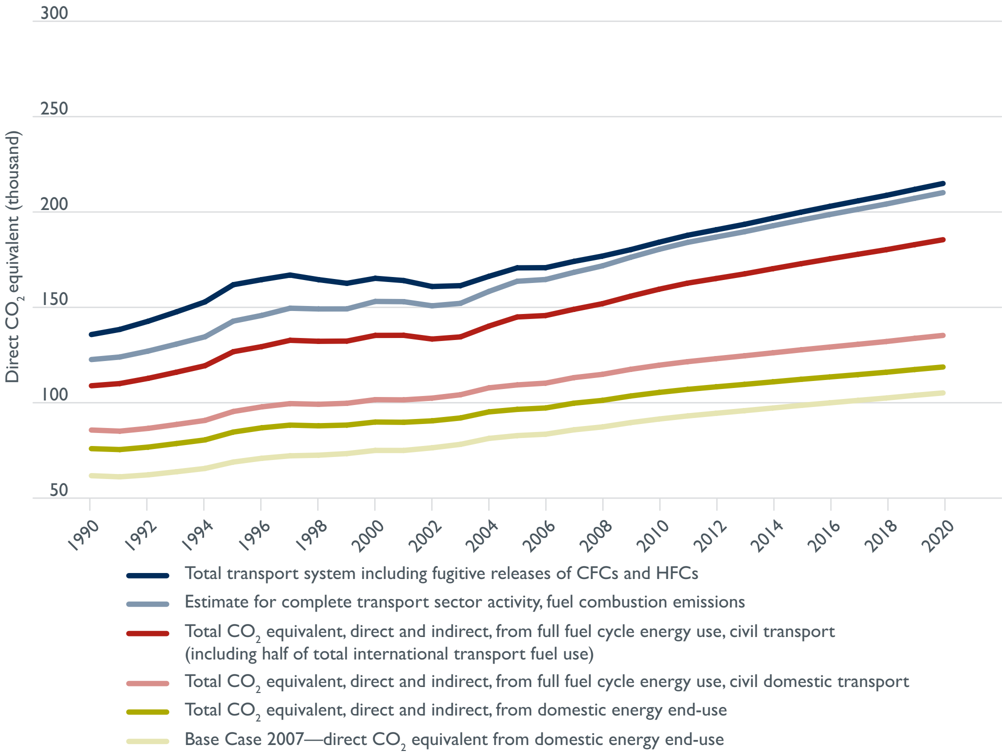
The resulting estimates for the total contribution of Australian transport activity to aggregate radiative forcing have 2007 values of approximately 168.4 million tonnes for total CO_2 equivalent emissions (direct and indirect effects) from transport energy use (on a full system cycle basis), and of around 174 million tonnes when including the effects of fugitive halocarbon releases. Under Base Case 2007 scenario assumptions, these totals are projected to increase close to 25 per cent by 2020, to respective levels of about 210.2 and 215 million tonnes of total CO_2 equivalent emissions. Such order-of-magnitude estimates for complete transport sector contributions to the anthropogenic greenhouse effect are around double the Kyoto-accounting totals (for direct CO_2 equivalent from domestic energy end use, as given in Table 1.2). These more representative transport emission totals (uppermost trend line of Figure 5.9) are not only considerably higher than the standard baseline level (lowermost trend line of Figure 5.9), but the overall shape and average growth rates of the respective curves are reasonably dissimilar.

Current direct emissions (CO_2 equivalent from CO_2, CH_4 and N_2O) due to domestic transport energy use (over the full fuel cycle) account for around 16 per cent of the national (direct) total. Including the indirect gas effects and re-allocating the effects of halocarbon releases from motor vehicle airconditioners to the transport sector, lifts this contribution to about 18 per cent (of a similarly calculated national total, for the estimated warming effects of CO_2, CH_4, N_2O, CO, NO_x, NMVOCs and synthetic gases such as HFCs). Adding the effects of international transport (using the 'half of total fuel use' allocation employed throughout this chapter) would further lift transport's share, to about 22 per cent (of total Australian emissions).

The report's final graph, Figure 5.10, is provided to give a demonstration of some preliminary results from ongoing BITRE research in this area, expanding both the amount of input detail that underlies the emission estimations, and the timeframes over which the historical and projection series are derived. Figure 5.10 gives estimates of total CO_2 equivalent emissions (direct and indirect) from Australian passenger cars, and displays how the various components of the total vary over the longer-term. A rough (indicative) estimate is also provided for the remaining element of transport-related radiative forcing that was omitted from previous tables and figures—the net effects of aerosols (here calculated from estimates of the black carbon portion of passenger vehicle particulate matter and sulphate formation due to vehicle emissions of SO_x and sulphurous particulates). Subsequent BITRE reports on transport greenhouse gas emissions will incorporate this level of detail (presented in Figure 5.10 for passenger cars), across all transport modes and vehicle types (e.g. see Cosgrove 2008).

Although the values derived in this section of the report are quite rough, and can suffer from a variety of possible evaluation or double-counting complications (typically absent from the standard inventory 'accounting' totals), they should serve as reasonable indicators of the actual impact, on overall warming levels (in terms of total CO_2 equivalent emissions), due to all Australian transport activity.

Figure 5.9 Comparison of the trend in direct CO_2 equivalent emissions from energy end use by Australian civil domestic transport, with a range of aggregate transport emission trends, 1990–2020

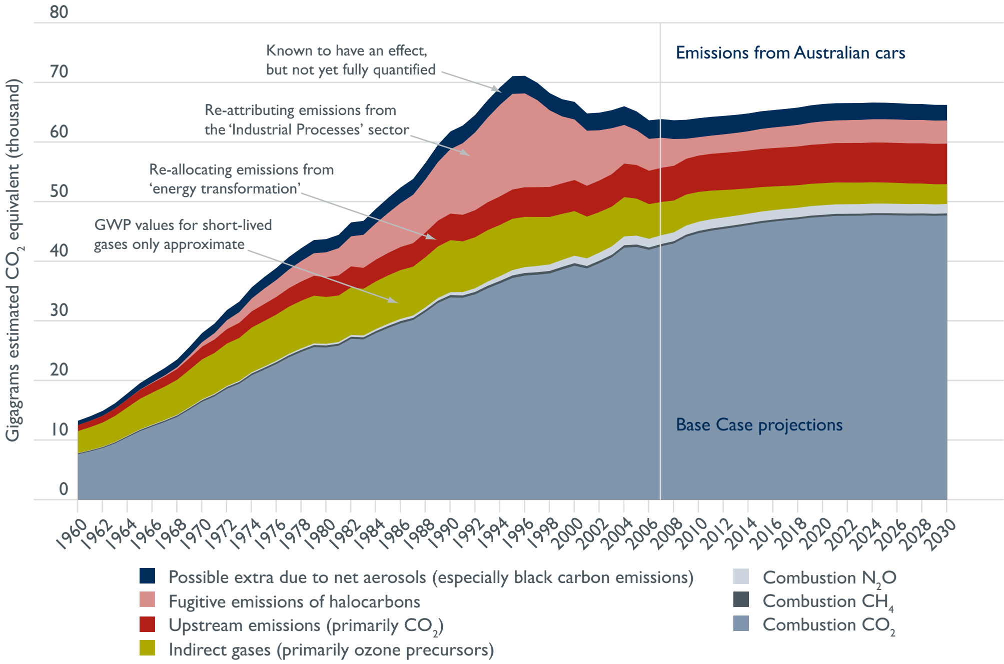


Notes: The transport sector/system estimates include total CO_2 equivalent emissions (both direct and indirect) for the full fuel cycle, and include all civil domestic transport, and half the fuel used by international transport to and from Australia, as well as Australian military fuel use, energy use by major oil and gas pipelines, and extra system cycle effects (i.e. emissions due to transport vehicle manufacture and disposal, and due to transport infrastructure construction and operation).

Total CO_2 equivalent values are estimates of the full radiative forcing effects of both direct gas species (CO_2, CH_4, N_2O) and indirect gas species (CO, NO_x and NMVOCs). The uppermost trend values also include the direct warming effects of halocarbon refrigerant releases from Australian transport vehicles. The indirect effects of particulate and SO_x emissions from transport are not included here.

Sources: BTCE (1995a, 1996a), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), Burnbank Consulting (2002), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1999, 2001, 2007a) and BITRE estimates.

Figure 5.10 Indicative estimation of the full greenhouse contribution of Australian passenger vehicles



Notes: The first three components, at the base of the graphed levels—direct CO_2 equivalent emissions of CO_2, CH_4 and N_2O from vehicle fuel combustion—are currently reported in the Transport section of the NGGI.

Estimated emission volumes of the indirectly radiative gas species CO, NO_x and NMVOCs are also included in the NGGI, as well as estimated SO_x emissions. Even though tonnages of indirect greenhouse gases are reported under UNFCCC and Kyoto guidelines, there is not yet agreement on fully accurate values for their Global Warming Potential (GWP) factors, and the NGGI does not yet assign CO_2 equivalent values to them. The fourth component here provides a rough estimate of their net radiative effects, for Australian passenger cars.

The fifth component of the graph allows for full fuel cycle effects, by re-allocating fuel processing emissions (that are due to the supply of energy for transport vehicle use) from the Energy Industries section of the NGGI to the relevant transport end uses.

The sixth component of the graph is based on estimated halocarbon (CFC and HFC) release from motor vehicle airconditioners, thus re-allocating some emissions covered by the Industrial Processes section of the NGGI.

The seventh, and uppermost, component is a very rough (indicative 'central') estimate of net aerosol effects due to passenger car SO_x and particulate emissions. The climatic effects of aerosols are complex and often difficult to suitably quantify (especially in basic GWP terms), and these approximate values are highly dependent on the chosen formation/deposition rates and radiative forcing factors assigned to black carbon particles and sulphates. The calculated net warming contribution can vary between slightly negative overall, to around double that displayed for the above central estimate, depending on which of the possible range of factors are chosen for the estimation process.

Sources: BTCE (1995a, 1996a), BTE (1999a), BTRE (2002a, 2003a, 2003c, 2006a), Burnbank Consulting (2002), Forster et al. (2006), Fuglestvedt et al. (2001), IPCC (1990, 1996, 1999, 2001, 2007a), Jacobson (2002), Reddy & Boucher (2007) and BITRE estimates, Reiterating the main point implied by this chapter's analysis: when considering the impact or likely effectiveness of emission abatement measures, quite different conclusions could possibly be reached if all the effects over the full transport system are allowed for, as opposed to just looking at changes in direct end use emission levels. The full abatement benefits of the measure could be significantly higher or lower than the estimated CO_2 changes imply, depending on how the measure's introduction is likely to alter a wide range of associated emissions outputs. Non-CO_2 vehicle emission rates will often vary independently of CO_2 emissions, particularly when dealing with technology-related options. An increase in upstream emissions (say, due to extra production required of new vehicles, or due to new types of fuel provision) may outweigh any end use energy benefits; or alternately, changes to downstream emissions (say, energy savings from improved vehicle recycling, or greater recovery of synthetic gas stores) may enhance initial benefits.

Appendix A Aggregate model inputs and detailed data series

Table A1 State and territory population projections

Year	*NSW*	*VIC*	*QLD*	*SA*	*WA*	*TAS*	*NT*	*ACT*	*Total*
				(thousand persons)					
1990	5 834	4 379	2 899	1 432	1 613	462	164	282	17 065
1991	5 899	4 420	2 961	1 446	1 636	467	165	289	17 284
1992	5 963	4 455	3 030	1 457	1 658	470	168	295	17 495
1993	6 005	4 472	3 110	1 461	1 678	472	171	299	17 667
1994	6 060	4 488	3 187	1 466	1 703	473	173	301	17 852
1995	6 127	4 517	3 265	1 469	1 734	474	178	305	18 069
1996	6 205	4 560	3 339	1 474	1 765	474	182	308	18 308
1997	6 277	4 597	3 395	1 481	1 795	474	187	309	18 515
1998	6 339	4 638	3 448	1 490	1 823	472	190	310	18 709
1999	6 411	4 686	3 501	1 498	1 850	471	193	312	18 923
2000	6 486	4 741	3 562	1 505	1 874	471	196	315	19 151
2001	6 575	4 805	3 629	1 512	1 901	472	198	319	19 411
2002	6 634	4 857	3 711	1 519	1 925	473	199	322	19 638
2003	6 682	4 911	3 801	1 526	1 950	477	199	323	19 870
2004	6 721	4 963	3 888	1 533	1 978	482	200	324	20 089
2005	6 769	5 023	3 977	1 542	2 011	486	203	326	20 337
2006	6 828	5 092	4 053	1 555	2 051	489	207	329	20 603
2007	6 893	5 141	4 127	1 561	2 082	491	210	332	20 836
Forecasts									
2008	6 961	5 193	4 203	1 568	2 113	493	213	334	21 079
2009	7 027	5 243	4 277	1 575	2 145	495	216	337	21 314
2010	7 093	5 294	4 353	1 581	2 176	496	219	340	21 552
2011	7 157	5 342	4 427	1 587	2 207	498	222	343	21 782
2012	7 217	5 388	4 500	1 592	2 237	499	225	345	22 003
2013	7 275	5 431	4 572	1 597	2 266	500	228	347	22 216
2014	7 333	5 475	4 645	1 601	2 296	501	230	350	22 430
2015	7 391	5 519	4 718	1 606	2 326	502	233	352	22 646
2016	7 446	5 561	4 790	1 609	2 355	503	236	354	22 853
2017	7 502	5 602	4 862	1 613	2 384	503	239	356	23 062
2018	7 554	5 642	4 933	1 616	2 412	503	242	358	23 261
2019	7 607	5 681	5 004	1 619	2 441	504	245	360	23 462
2020	7 661	5 721	5 076	1 622	2 469	504	248	362	23 664

Sources: BITRE estimates based on ABS (mid-range, 'series B') long-term projections, available at the time of study's preparation (ABS 2006c).

Table A2 Capital city population projections—Statistical Division

Year	Sydney	Melbourne	Brisbane	Adelaide	Perth	Hobart	Darwin	Canberra	Total
				(thousand persons in metropolitan area)					
1990	3 610	3 108	1 304	1 042	1 164	188	87	281	10 786
1991	3 650	3 134	1 332	1 051	1 180	190	88	288	10 913
1992	3 690	3 161	1 362	1 057	1 198	191	89	293	11 041
1993	3 724	3 179	1 397	1 062	1 215	193	90	297	11 158
1994	3 759	3 195	1 427	1 065	1 236	193	91	300	11 265
1995	3 802	3 221	1 459	1 066	1 260	194	93	303	11 398
1996	3 881	3 283	1 501	1 078	1 295	196	96	308	11 638
1997	3 929	3 310	1 524	1 084	1 316	196	99	309	11 766
1998	3 970	3 342	1 549	1 091	1 335	196	101	310	11 893
1999	4 020	3 380	1 572	1 097	1 355	196	103	312	12 035
2000	4 069	3 423	1 599	1 102	1 373	196	105	315	12 182
2001	4 128	3 472	1 629	1 108	1 393	197	107	319	12 353
2002	4 167	3 513	1 668	1 114	1 412	198	108	321	12 501
2003	4 199	3 555	1 712	1 119	1 431	200	108	323	12 647
2004	4 225	3 593	1 753	1 123	1 455	202	109	324	12 784
2005	4 256	3 636	1 791	1 129	1 478	204	111	325	12 930
2006	4 293	3 684	1 820	1 139	1 508	206	114	328	13 093
2007	4 336	3 725	1 858	1 144	1 533	207	116	331	13 251
Forecasts									
2008	4 380	3 768	1 897	1 150	1 558	208	119	334	13 415
2009	4 423	3 810	1 936	1 155	1 584	209	121	337	13 575
2010	4 466	3 852	1 976	1 161	1 609	211	123	340	13 736
2011	4 507	3 892	2 014	1 166	1 634	212	126	342	13 893
2012	4 546	3 930	2 053	1 170	1 659	213	128	345	14 044
2013	4 584	3 967	2 091	1 174	1 683	214	130	347	14 190
2014	4 622	4 005	2 130	1 178	1 707	215	133	349	14 338
2015	4 660	4 042	2 169	1 182	1 732	216	135	352	14 487
2016	4 696	4 078	2 207	1 186	1 756	217	138	354	14 630
2017	4 732	4 114	2 247	1 189	1 780	217	140	356	14 775
2018	4 767	4 149	2 285	1 192	1 803	218	142	358	14 914
2019	4 801	4 183	2 324	1 195	1 827	219	145	360	15 054
2020	4 836	4 218	2 363	1 198	1 851	219	147	362	15 196

Sources: BITRE estimates based on ABS (mid-range, 'series B') long-term projections, then available (ABS 2006c).

Table A3 Base case Australian GDP growth assumptions

Financial year	*Average annual real GDP growth (per cent per annum)*
2000–2005	3.12
2005–2010	3.11
2010–2015	2.72
2015–2020	2.42

Source: Treasury estimates, (pers. comm. 2007).

Road transport time series estimates are partially based on data collected by the ABS *Survey of Motor Vehicle Use*—which have been appropriately scaled and standardised, according to the methods described in Cosgrove and Mitchell (2001), to allow for methodological variations between the various survey years—and on fuel sales data from the monthly *Australian Petroleum Statistics* collection (DITR/RET).

Table A4 Base case projections of national road freight task by type of vehicle

Financial year	*Light commercial vehicles*	*Rigid trucks*	*Articulated trucks*	*Total*
		(billion tonne kilometres)		
1990	4.7	22.8	63.2	90.6
1991	4.6	20.9	62.5	88.0
1992	4.7	20.3	63.0	88.0
1993	4.9	20.0	68.1	92.9
1994	5.0	20.6	71.5	97.2
1995	5.3	21.8	77.5	104.6
1996	5.5	23.0	82.3	110.8
1997	5.6	24.8	86.5	116.9
1998	5.9	25.3	91.8	123.0
1999	6.1	25.3	97.2	128.6
2000	6.3	26.2	103.8	136.3
2001	6.4	26.0	106.4	138.8
2002	6.7	27.2	112.8	146.6
2003	6.9	28.4	117.7	153.0
2004	7.1	29.3	123.9	160.3
2005	7.3	30.6	128.7	166.5
2006	7.4	32.4	134.0	173.7
2007	7.5	34.0	142.1	183.6
Forecasts				
2008	7.7	35.0	148.1	190.8
2009	8.0	36.0	154.6	198.6
2010	8.2	36.9	162.3	207.4
2011	8.5	37.6	170.4	216.6
2012	8.8	38.1	178.0	224.9
2013	9.2	38.5	185.5	233.1
2014	9.5	39.0	192.7	241.2
2015	9.8	39.6	200.0	249.3
2016	10.1	40.2	207.2	257.4
2017	10.4	40.7	214.6	265.8
2018	10.8	41.2	222.4	274.3
2019	11.1	41.9	230.0	283.0
2020	11.5	42.5	237.7	291.6

Sources: ABARE (2007a), ABS (2006a and earlier years), BTE (1999a), BTRE (2007a, 2006a, 2006b, 2003a, 2003c, 2002a), DITR (2007a) and BITRE estimates.

Table A5 Base case projections of national vehicle kilometres travelled by type of vehicle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(billion kilometres)			
1990	124.01	23.90	6.84	4.14	1.48	1.80	162.18
1991	124.47	23.30	6.12	4.08	1.44	1.62	161.04
1992	127.19	24.17	5.91	4.11	1.42	1.61	164.40
1993	131.34	24.95	5.82	4.40	1.43	1.62	169.55
1994	134.91	25.76	6.02	4.50	1.49	1.59	174.26
1995	139.38	27.27	6.32	4.80	1.54	1.57	180.88
1996	141.59	28.28	6.65	5.02	1.58	1.52	184.64
1997	142.87	28.65	7.15	5.21	1.58	1.52	186.99
1998	144.51	29.94	7.24	5.40	1.62	1.46	190.17
1999	148.08	30.69	7.17	5.55	1.65	1.40	194.55
2000	151.17	31.33	7.29	5.70	1.68	1.42	198.59
2001	149.75	31.70	7.12	5.63	1.75	1.46	197.42
2002	153.63	32.94	7.38	5.80	1.76	1.48	202.99
2003	157.71	34.02	7.66	5.97	1.80	1.52	208.68
2004	163.95	35.15	7.85	6.16	1.84	1.66	216.61
2005	164.62	35.38	8.16	6.34	1.85	1.73	218.08
2006	163.79	35.92	8.58	6.47	1.86	1.81	218.43
2007	167.04	36.54	8.97	6.77	1.90	1.95	223.17
Forecasts							
2008	169.60	37.54	9.19	6.91	1.94	2.01	227.18
2009	174.52	38.57	9.42	7.10	1.98	2.06	233.64
2010	177.91	39.85	9.60	7.34	2.02	2.11	238.83
2011	180.71	41.20	9.74	7.60	2.05	2.15	243.46
2012	183.10	42.56	9.81	7.86	2.09	2.20	247.62
2013	185.40	43.91	9.86	8.11	2.13	2.25	251.67
2014	187.76	45.26	9.95	8.34	2.17	2.30	255.78
2015	190.20	46.64	10.04	8.57	2.21	2.35	260.01
2016	192.31	48.01	10.14	8.79	2.26	2.40	263.91
2017	194.33	49.46	10.22	9.02	2.30	2.45	267.79
2018	196.25	50.92	10.30	9.25	2.35	2.50	271.56
2019	198.56	52.39	10.42	9.47	2.39	2.55	275.78
2020	200.31	53.87	10.51	9.69	2.44	2.60	279.43

Notes: 'Passenger car' results in all tables include 4WD passenger vehicles ('All Terrain Wagons'—ATWs), unless explicitly noted otherwise.

LCV (light commercial vehicle) fleet results include the (generally) heavier 4WD vehicles primarily purchased for business uses.

Sources: ABARE (2007a), ABS (2006a and earlier), BTE (1999a), BTRE (2007a, 2006a, 2003a, 2003c, 2002a), DITR (2007a) and BITRE estimates.

Table A6 Base case projections of metropolitan and non-metropolitan vehicle kilometres travelled for passenger vehicles, 1990–2020

Financial year	*Metropolitan cars*	*Non-metropolitan cars*	*Total*
		(billion kilometres)	
1990	73.34	50.67	124.01
1991	73.60	50.88	124.47
1992	75.21	51.98	127.19
1993	77.72	53.61	131.34
1994	79.91	55.00	134.91
1995	82.64	56.73	139.38
1996	84.04	57.55	141.59
1997	84.94	57.93	142.87
1998	86.04	58.47	144.51
1999	88.22	59.86	148.08
2000	90.29	60.88	151.17
2001	89.60	60.15	149.75
2002	92.05	61.58	153.63
2003	94.61	63.10	157.71
2004	98.49	65.46	163.95
2005	99.02	65.60	164.62
2006	98.65	65.14	163.79
2007	100.73	66.31	167.04
Forecasts			
2008	102.41	67.20	169.60
2009	105.51	69.01	174.52
2010	107.70	70.22	177.91
2011	109.53	71.18	180.71
2012	111.11	71.99	183.10
2013	112.65	72.75	185.40
2014	114.22	73.53	187.76
2015	115.85	74.35	190.20
2016	117.29	75.03	192.31
2017	118.66	75.67	194.33
2018	119.99	76.27	196.25
2019	121.55	77.01	198.56
2020	122.77	77.54	200.31

Note: 'Metropolitan' results refer to all activity within the greater metropolitan areas (Statistical Division) of the eight state and territory capital cities.

Sources: ABS (2006a and earlier), BTE (1999a), BTRE (2007a, 2006a, 2003a, 2003c, 2002a), DITR (2007a), DITR (2007a), and BITRE estimates.

Table A7 Base case projections of carbon dioxide (CO_2) emissions for Australian road transport by type of vehicle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(gigagrams)			
1990	33 932	7 601	5 031	5 593	1 231	242	53 629
1991	33 871	7 300	4 500	5 509	1 189	214	52 582
1992	34 450	7 501	4 335	5 556	1 160	214	53 216
1993	35 458	7 691	4 275	5 970	1 145	214	54 753
1994	36 281	7 869	4 425	6 148	1 181	211	56 115
1995	37 180	8 267	4 662	6 616	1 202	208	58 137
1996	37 593	8 522	4 936	6 959	1 219	202	59 431
1997	37 727	8 534	5 315	7 267	1 210	201	60 254
1998	37 935	9 000	5 394	7 579	1 225	193	61 327
1999	38 614	9 260	5 362	7 844	1 236	186	62 503
2000	39 242	9 479	5 450	8 099	1 243	187	63 699
2001	38 781	9 629	5 328	8 032	1 276	190	63 236
2002	39 672	10 080	5 519	8 309	1 264	194	65 038
2003	40 656	10 427	5 741	8 617	1 309	203	66 954
2004	42 263	10 843	5 867	8 941	1 332	221	69 468
2005	42 399	10 958	6 085	9 232	1 329	229	70 232
2006	41 918	11 084	6 364	9 454	1 311	239	70 369
2007	42 513	11 290	6 622	9 899	1 329	256	71 909
Forecasts							
2008	42 984	11 553	6 746	10 118	1 336	263	72 999
2009	44 096	11 822	6 884	10 419	1 344	268	74 832
2010	44 711	12 167	6 993	10 787	1 356	274	76 288
2011	45 118	12 528	7 067	11 172	1 366	280	77 530
2012	45 420	12 921	7 097	11 563	1 376	284	78 662
2013	45 727	13 292	7 129	11 953	1 396	290	79 786
2014	46 048	13 661	7 192	12 314	1 416	294	80 925
2015	46 392	14 041	7 256	12 668	1 440	300	82 097
2016	46 640	14 431	7 342	13 014	1 471	304	83 202
2017	46 859	14 857	7 415	13 372	1 508	307	84 317
2018	47 039	15 287	7 484	13 741	1 540	311	85 400
2019	47 304	15 729	7 592	14 095	1 575	317	86 612
2020	47 445	16 200	7 688	14 451	1 609	321	87 714

Notes: Emission values based on the assumption of full carbon combustion (apart from unburnt portion released as fine solids) for transport fuels.

Energy supply emissions are not included. Biomass derived emissions (i.e. CO_2 emissions from the combustion of biofuels) are also not included.

Gigagrams = 10^9 grams, equivalent to thousand tonnes.

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A8 Base case projections of methane (CH_4) emissions for Australian road transport by type of vehicle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(gigagrams)			
1990	18.42	2.86	0.71	0.19	0.16	0.25	22.59
1991	18.43	2.84	0.61	0.19	0.17	0.23	22.46
1992	18.83	2.95	0.57	0.19	0.18	0.22	22.94
1993	19.42	3.06	0.55	0.20	0.18	0.22	23.63
1994	19.89	3.15	0.54	0.21	0.19	0.22	24.20
1995	20.43	3.34	0.55	0.21	0.20	0.22	24.94
1996	20.51	3.49	0.54	0.21	0.20	0.21	25.16
1997	20.49	3.62	0.53	0.21	0.20	0.21	25.25
1998	20.42	3.71	0.50	0.21	0.21	0.20	25.23
1999	20.44	3.77	0.46	0.20	0.21	0.19	25.28
2000	20.35	3.78	0.44	0.19	0.22	0.19	25.16
2001	19.50	3.72	0.40	0.18	0.22	0.19	24.22
2002	19.43	3.73	0.38	0.18	0.24	0.19	24.16
2003	19.47	3.80	0.35	0.18	0.25	0.20	24.24
2004	19.68	3.83	0.33	0.18	0.24	0.22	24.47
2005	19.02	3.78	0.31	0.18	0.24	0.22	23.73
2006	18.20	3.71	0.30	0.17	0.23	0.23	22.85
2007	17.86	3.69	0.29	0.18	0.23	0.25	22.50
Forecasts							
2008	17.51	3.70	0.28	0.17	0.23	0.26	22.16
2009	17.62	3.70	0.27	0.18	0.23	0.26	22.25
2010	17.40	3.70	0.26	0.18	0.23	0.27	22.03
2011	17.04	3.68	0.25	0.18	0.23	0.27	21.65
2012	16.70	3.65	0.25	0.18	0.23	0.28	21.28
2013	16.39	3.61	0.24	0.19	0.23	0.28	20.94
2014	16.13	3.59	0.23	0.19	0.23	0.29	20.66
2015	15.95	3.53	0.23	0.19	0.24	0.29	20.42
2016	15.90	3.50	0.23	0.19	0.24	0.29	20.35
2017	15.76	3.45	0.22	0.20	0.25	0.30	20.17
2018	15.77	3.41	0.22	0.20	0.26	0.30	20.16
2019	15.83	3.37	0.22	0.20	0.27	0.31	20.20
2020	15.85	3.30	0.22	0.21	0.28	0.31	20.16

Note: Energy supply emissions are not included.

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A9 Base case projections of nitrous oxide (N_2O) emissions for Australian road transport by type of vehicle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(gigagrams)			
1990	1.566	0.140	0.170	0.104	0.037	0.005	2.022
1991	1.808	0.188	0.153	0.102	0.036	0.005	2.292
1992	2.042	0.239	0.147	0.103	0.035	0.005	2.571
1993	2.317	0.285	0.146	0.110	0.036	0.005	2.898
1994	2.600	0.332	0.151	0.113	0.037	0.005	3.238
1995	2.912	0.384	0.159	0.120	0.038	0.005	3.618
1996	3.171	0.432	0.168	0.126	0.039	0.005	3.941
1997	3.362	0.479	0.180	0.131	0.040	0.005	4.196
1998	3.555	0.517	0.182	0.135	0.041	0.004	4.435
1999	3.812	0.559	0.182	0.139	0.042	0.004	4.738
2000	4.042	0.601	0.185	0.143	0.043	0.004	5.019
2001	4.134	0.634	0.182	0.141	0.045	0.004	5.141
2002	4.388	0.667	0.190	0.146	0.046	0.004	5.441
2003	4.588	0.712	0.197	0.150	0.046	0.005	5.699
2004	4.814	0.756	0.203	0.155	0.048	0.005	5.981
2005	4.787	0.775	0.212	0.160	0.049	0.005	5.989
2006	4.708	0.778	0.224	0.164	0.050	0.005	5.929
2007	4.769	0.801	0.237	0.171	0.052	0.006	6.035
Forecasts							
2008	4.812	0.832	0.245	0.175	0.054	0.006	6.124
2009	4.942	0.859	0.253	0.180	0.056	0.006	6.296
2010	5.007	0.888	0.261	0.187	0.058	0.006	6.407
2011	5.048	0.918	0.267	0.194	0.061	0.006	6.494
2012	5.070	0.946	0.272	0.201	0.063	0.007	6.559
2013	5.087	0.969	0.276	0.207	0.065	0.007	6.612
2014	5.105	0.994	0.281	0.214	0.067	0.007	6.668
2015	5.126	1.009	0.285	0.220	0.069	0.007	6.717
2016	5.135	1.021	0.290	0.226	0.071	0.007	6.750
2017	5.141	1.037	0.295	0.232	0.073	0.007	6.784
2018	5.150	1.049	0.298	0.239	0.074	0.007	6.819
2019	5.173	1.060	0.304	0.245	0.076	0.008	6.866
2020	5.181	1.055	0.309	0.252	0.077	0.008	6.881

Note: Energy supply emissions are not included.
Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A10 Base case projections of carbon monoxide (CO) emissions for Australian road transport by type of vehicle

Year	Cars	Light commercial vehicles	Rigid and other trucks	Articulated trucks	Buses	Motorcycles	Total
				(gigagrams)			
1990	3 283	552	99.4	30.6	19.1	26.9	4 012
1991	3 205	531	86.0	30.1	18.6	24.1	3 894
1992	3 211	537	79.8	30.4	18.2	24.0	3 901
1993	3 235	544	77.1	32.5	18.2	23.9	3 931
1994	3 223	549	76.1	33.0	18.9	23.4	3 923
1995	3 223	577	76.4	34.5	18.8	23.0	3 953
1996	3 147	591	74.9	35.5	18.7	22.2	3 889
1997	3 062	595	74.7	36.3	18.7	22.0	3 809
1998	2 953	591	71.0	36.6	19.1	21.1	3 691
1999	2 847	581	66.9	36.3	19.0	20.1	3 570
2000	2 746	567	64.7	35.7	18.8	20.3	3 452
2001	2 561	542	59.4	34.2	19.0	20.8	3 236
2002	2 475	536	58.8	34.0	18.6	20.9	3 143
2003	2 416	529	55.4	33.9	18.7	21.4	3 075
2004	2 369	517	51.5	33.7	18.5	23.2	3 013
2005	2 225	492	48.6	33.6	17.9	24.0	2 842
2006	2 071	482	48.2	33.4	17.2	25.0	2 677
2007	1 974	469	47.2	33.7	16.8	26.9	2 568
Forecasts							
2008	1 877	465	46.6	33.3	16.4	27.5	2 466
2009	1 815	458	45.8	33.1	15.9	28.1	2 396
2010	1 735	452	45.0	33.2	15.5	28.6	2 310
2011	1 652	446	44.3	33.4	15.1	29.1	2 220
2012	1 571	437	43.5	33.7	14.7	29.6	2 129
2013	1 496	428	42.6	34.0	14.2	30.1	2 044
2014	1 427	419	42.1	34.3	13.8	30.6	1 967
2015	1 367	408	41.8	34.7	13.7	31.1	1 896
2016	1 310	396	41.5	34.8	13.5	31.6	1 828
2017	1 255	385	41.2	34.9	13.4	32.1	1 762
2018	1 225	377	40.9	35.2	13.2	32.6	1 725
2019	1 207	369	41.0	35.5	13.3	33.1	1 700
2020	1 188	361	41.1	36.0	13.3	33.6	1 673

Note: Energy supply emissions are not included.
Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A11 Base case projections of carbon monoxide (CO) emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams)		
1990	4 018	4.9	120.7	117.3	4 261
1991	3 901	4.9	122.6	98.3	4 127
1992	3 907	4.8	129.0	93.6	4 135
1993	3 937	4.7	136.4	98.8	4 177
1994	3 930	5.1	143.6	96.3	4 175
1995	3 961	4.9	152.1	99.1	4 217
1996	3 896	4.8	159.1	97.1	4 157
1997	3 817	4.9	164.5	98.1	4 084
1998	3 699	5.0	169.3	97.8	3 971
1999	3 578	5.1	176.4	98.3	3 858
2000	3 460	5.3	183.8	97.6	3 746
2001	3 244	5.2	186.8	95.6	3 532
2002	3 151	5.4	195.4	89.6	3 442
2003	3 084	5.5	205.4	86.1	3 381
2004	3 022	6.0	218.7	83.5	3 330
2005	2 851	6.4	224.8	84.7	3 167
2006	2 686	6.6	194.9	81.9	2 970
2007	2 577	6.8	196.5	84.5	2 865
Forecasts					
2008	2 476	7.1	197.9	86.9	2 768
2009	2 406	7.4	199.2	89.1	2 702
2010	2 319	7.7	200.5	89.4	2 617
2011	2 230	7.9	201.7	89.7	2 529
2012	2 139	8.1	202.7	90.0	2 440
2013	2 054	8.2	203.6	90.1	2 356
2014	1 978	8.4	204.6	90.3	2 281
2015	1 906	8.6	205.5	90.4	2 211
2016	1 839	8.7	206.4	90.5	2 144
2017	1 772	8.9	207.2	90.6	2 079
2018	1 735	9.0	207.9	90.6	2 043
2019	1 710	9.1	208.7	90.7	2 019
2020	1 684	9.3	209.4	90.7	1 993

Notes: 'Motor vehicles' includes all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation).

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A12 Base case projections of nitrogen oxide (NO_x) emissions for Australian road transport by type of vehicle

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(gigagrams)			
1990	233.2	51.3	62.6	69.6	16.5	0.90	434.1
1991	235.9	50.7	55.2	68.3	15.8	0.80	426.7
1992	245.4	53.4	52.7	68.3	15.4	0.80	436.0
1993	252.1	55.4	51.5	72.7	15.2	0.80	447.6
1994	256.9	57.2	52.9	73.7	15.7	0.78	457.2
1995	263.3	61.0	55.1	77.8	15.9	0.77	473.9
1996	265.7	63.6	57.6	79.6	16.1	0.74	483.3
1997	265.1	65.3	61.3	80.0	15.9	0.73	488.4
1998	262.1	67.5	61.3	80.1	16.1	0.70	487.8
1999	260.2	68.9	59.6	79.5	16.0	0.67	484.9
2000	257.9	69.8	59.2	79.2	16.0	0.68	482.8
2001	247.2	69.7	56.7	75.9	16.3	0.69	466.4
2002	245.3	71.3	57.4	75.5	16.0	0.70	466.3
2003	243.4	72.3	58.1	75.7	16.2	0.71	466.5
2004	243.3	72.4	58.0	75.5	16.3	0.77	466.2
2005	231.9	69.6	58.8	75.0	16.0	0.80	452.0
2006	218.4	67.9	59.9	74.6	15.6	0.83	437.2
2007	210.3	65.5	60.5	75.1	15.6	0.90	427.9
Forecasts							
2008	201.6	63.9	59.6	73.4	15.3	0.92	414.7
2009	196.1	62.0	58.5	72.3	15.0	0.94	404.9
2010	188.6	60.4	57.3	71.9	14.8	0.95	393.9
2011	180.8	59.0	56.0	71.7	14.5	0.97	383.0
2012	172.9	57.4	54.5	71.7	14.3	0.99	371.8
2013	165.4	55.9	53.1	71.4	14.0	1.00	360.8
2014	158.7	54.8	52.0	71.0	13.7	1.02	351.1
2015	152.7	53.6	51.0	70.7	13.5	1.04	342.5
2016	147.2	52.5	50.2	70.4	13.3	1.05	334.6
2017	142.0	51.7	49.3	70.1	13.2	1.07	327.3
2018	138.3	51.3	48.5	70.1	13.0	1.09	322.2
2019	135.8	51.0	48.0	70.1	13.0	1.10	319.0
2020	133.5	50.7	47.6	70.4	13.0	1.12	316.2

Note: Energy supply emissions are not included.
Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A13 Base case projections of nitrogen oxide (NO_x) emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams)		
1990	434.5	39.6	45.1	17.6	536.8
1991	427.2	39.4	36.5	18.9	521.9
1992	436.5	38.2	36.7	19.7	531.0
1993	448.1	37.6	30.6	20.6	537.0
1994	457.7	40.6	26.5	21.3	546.0
1995	474.4	39.4	38.4	23.7	575.9
1996	483.8	38.3	40.8	24.9	587.8
1997	488.9	39.0	39.2	25.8	593.0
1998	488.3	39.6	31.0	24.1	583.1
1999	485.4	40.7	23.2	23.5	572.8
2000	483.4	42.2	24.3	24.1	573.9
2001	467.0	41.4	21.8	25.7	555.9
2002	466.9	43.3	21.3	23.0	554.4
2003	467.1	44.4	20.5	22.1	554.2
2004	466.8	47.6	21.6	22.7	558.7
2005	452.7	51.1	23.3	24.0	551.1
2006	437.9	52.7	25.5	25.3	541.4
2007	428.6	54.4	27.0	26.9	536.9
Forecasts					
2008	415.4	57.2	28.1	27.6	528.2
2009	405.6	59.4	29.1	28.3	522.4
2010	394.6	61.5	30.2	28.9	515.2
2011	383.7	63.4	30.9	29.4	507.4
2012	372.5	64.5	31.0	29.9	497.9
2013	361.6	65.7	31.1	30.3	488.6
2014	351.8	67.2	31.3	30.6	481.0
2015	343.2	68.6	31.5	30.9	474.2
2016	335.3	69.8	31.6	31.1	467.9
2017	328.1	71.0	31.7	31.3	462.1
2018	323.0	72.1	31.6	31.5	458.2
2019	319.8	73.2	31.6	31.7	456.4
2020	317.0	74.4	31.7	31.9	455.0

Notes: 'Motor vehicles' includes all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation).

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A14 Base case projections of non-methane volatile organic compound (NMVOC) emissions for Australian road transport by type of vehicle

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(gigagrams)			
1990	518.7	79.8	24.5	9.8	5.6	7.7	646.1
1991	497.7	75.0	21.5	9.6	5.4	6.9	616.1
1992	493.3	74.1	20.3	9.6	5.2	6.9	609.4
1993	495.2	74.1	19.7	10.3	5.2	6.9	611.3
1994	487.4	72.7	19.8	10.4	5.3	6.7	602.4
1995	484.2	75.2	20.3	10.8	5.3	6.7	602.4
1996	469.4	76.0	20.5	10.7	5.2	6.4	588.4
1997	454.6	75.9	21.0	10.6	5.1	6.4	573.6
1998	438.8	74.5	20.2	10.4	5.0	6.1	555.1
1999	425.3	72.8	19.1	10.0	4.9	5.9	538.0
2000	411.7	70.3	18.3	9.7	4.8	5.9	520.7
2001	385.2	66.8	16.9	9.2	4.7	6.1	488.8
2002	373.2	65.4	16.5	9.0	4.5	6.1	474.7
2003	366.4	64.7	15.9	8.9	4.5	6.3	466.6
2004	364.9	63.8	15.0	8.8	4.4	6.8	463.6
2005	346.6	60.8	14.4	8.8	4.2	7.0	441.8
2006	325.9	59.3	14.0	8.7	4.0	7.3	419.2
2007	315.4	57.7	13.6	8.8	3.8	7.9	407.2
Forecasts							
2008	308.3	58.0	13.0	8.8	3.7	8.1	399.9
2009	303.8	57.3	12.5	8.8	3.5	8.3	394.2
2010	296.9	56.8	12.0	8.9	3.4	8.5	386.5
2011	289.9	56.2	11.5	9.1	3.3	8.6	378.7
2012	283.3	55.5	11.1	9.3	3.2	8.8	371.1
2013	277.6	54.6	10.7	9.4	3.1	8.9	364.3
2014	272.9	53.8	10.5	9.6	3.0	9.1	358.8
2015	269.3	52.5	10.3	9.6	2.9	9.3	354.0
2016	266.2	51.1	10.1	9.7	2.9	9.4	349.4
2017	263.4	49.9	9.8	9.9	2.8	9.6	345.4
2018	262.2	48.8	9.6	10.1	2.8	9.8	343.3
2019	262.2	47.6	9.6	10.2	2.8	9.9	342.3
2020	262.2	46.5	9.5	10.3	2.8	10.1	341.4

Note: Energy supply emissions are not included.
Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A15 Base case projections of non-methane volatile organic compound (NMVOC) emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams)		
1990	648.0	2.47	20.46	2.96	673.9
1991	618.0	2.46	20.54	2.80	643.8
1992	611.3	2.39	21.55	2.79	638.0
1993	613.2	2.35	22.57	2.94	641.1
1994	604.4	2.54	23.56	2.96	633.4
1995	604.5	2.46	25.23	3.18	635.3
1996	590.5	2.39	26.38	3.25	622.5
1997	575.7	2.44	27.20	3.34	608.7
1998	557.3	2.48	27.75	3.21	590.8
1999	540.2	2.55	28.66	3.16	574.6
2000	523.1	2.64	29.88	3.20	558.8
2001	491.1	2.59	30.32	3.30	527.3
2002	477.1	2.70	31.68	3.00	514.5
2003	469.1	2.77	33.25	2.87	508.0
2004	466.2	2.98	35.40	2.87	507.5
2005	444.5	3.20	36.37	2.99	487.0
2006	421.8	3.30	31.66	3.05	459.8
2007	409.9	3.40	31.96	3.21	448.4
Forecasts					
2008	402.6	3.57	32.21	3.30	441.6
2009	396.9	3.71	32.43	3.38	436.5
2010	389.2	3.85	32.67	3.43	429.2
2011	381.4	3.96	32.87	3.48	421.7
2012	373.8	4.03	33.03	3.52	414.4
2013	367.1	4.11	33.18	3.55	407.9
2014	361.6	4.20	33.34	3.58	402.7
2015	356.8	4.29	33.49	3.60	398.2
2016	352.2	4.36	33.63	3.62	393.8
2017	348.3	4.44	33.77	3.63	390.1
2018	346.1	4.50	33.88	3.65	388.1
2019	345.2	4.57	34.00	3.66	387.4
2020	344.2	4.65	34.12	3.68	386.7

Notes: 'Motor vehicles' includes all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation).

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A16 Base case projections of sulphur oxide (SO_x) emissions for Australian road transport by type of vehicle

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total*
				(gigagrams)			
1990	9.701	4.006	6.126	7.627	1.382	0.027	28.869
1991	9.101	3.549	5.263	7.177	1.272	0.023	26.385
1992	8.534	3.532	4.858	6.895	1.186	0.022	25.027
1993	8.073	3.459	4.561	7.038	1.124	0.021	24.275
1994	7.503	3.338	4.505	6.867	1.108	0.019	23.340
1995	7.137	3.298	4.514	6.980	1.078	0.018	23.025
1996	6.649	3.161	4.543	6.911	1.040	0.017	22.320
1997	6.248	2.827	4.622	6.766	0.975	0.016	21.454
1998	5.984	3.014	4.408	6.587	0.925	0.015	20.933
1999	5.719	2.810	3.782	5.844	0.806	0.013	18.975
2000	5.331	2.522	3.214	5.030	0.680	0.013	16.790
2001	5.092	2.411	2.842	4.493	0.633	0.012	15.483
2002	4.857	2.385	2.624	4.137	0.554	0.012	14.569
2003	4.596	1.794	1.728	2.676	0.363	0.012	11.169
2004	4.486	1.388	1.071	1.666	0.226	0.012	8.850
2005	4.125	1.127	0.748	1.146	0.153	0.012	7.311
2006	3.701	0.828	0.394	0.587	0.079	0.012	5.602
2007	3.482	0.752	0.329	0.492	0.066	0.012	5.134
Forecasts							
2008	3.236	0.648	0.212	0.315	0.044	0.012	4.466
2009	3.312	0.638	0.132	0.195	0.030	0.012	4.320
2010	3.267	0.614	0.092	0.135	0.023	0.012	4.143
2011	3.188	0.583	0.050	0.070	0.016	0.012	3.919
2012	3.101	0.580	0.050	0.072	0.016	0.012	3.831
2013	2.995	0.572	0.050	0.075	0.016	0.012	3.721
2014	2.871	0.563	0.051	0.077	0.016	0.012	3.591
2015	2.728	0.546	0.051	0.079	0.017	0.012	3.433
2016	2.560	0.523	0.051	0.081	0.017	0.012	3.245
2017	2.401	0.499	0.052	0.084	0.017	0.012	3.065
2018	2.247	0.468	0.052	0.086	0.018	0.012	2.883
2019	2.112	0.429	0.053	0.088	0.018	0.012	2.713
2020	1.961	0.377	0.054	0.090	0.018	0.012	2.512

Note: Energy supply emissions are not included.
Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A17 Base case projections of sulphur oxide (SO_x) emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams)		
1990	28.88	1.48	26.06	1.12	57.55
1991	26.39	1.47	21.54	1.43	50.83
1992	25.03	1.42	20.86	1.55	48.87
1993	24.28	1.39	17.42	1.62	44.72
1994	23.35	1.50	14.18	1.72	40.74
1995	23.03	1.45	19.80	2.03	46.30
1996	22.33	1.40	20.22	2.22	46.17
1997	21.46	1.42	19.10	2.37	44.34
1998	20.94	1.44	14.80	2.13	39.30
1999	18.98	1.47	11.34	2.03	33.82
2000	16.80	1.52	12.65	2.12	33.08
2001	15.49	1.48	11.21	2.36	30.54
2002	14.57	1.55	10.44	2.10	28.67
2003	11.17	1.58	10.25	1.99	25.00
2004	8.85	1.69	11.10	2.08	23.72
2005	7.32	1.81	11.68	2.21	23.01
2006	5.61	1.85	12.12	2.45	22.03
2007	5.14	1.90	12.90	2.66	22.60
Forecasts					
2008	4.47	1.99	13.38	2.72	22.56
2009	4.32	2.07	13.83	2.79	23.02
2010	4.15	2.13	14.34	2.87	23.48
2011	3.92	2.18	14.63	2.94	23.68
2012	3.84	2.22	14.57	2.99	23.61
2013	3.73	2.25	14.55	3.04	23.56
2014	3.60	2.29	14.59	3.08	23.55
2015	3.44	2.33	14.60	3.11	23.48
2016	3.25	2.36	14.60	3.14	23.35
2017	3.07	2.39	14.54	3.17	23.16
2018	2.89	2.41	14.45	3.19	22.94
2019	2.72	2.44	14.37	3.21	22.75
2020	2.52	2.47	14.32	3.24	22.54

Notes: 'Motor vehicles' includes all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation).

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A18 Base case projections of particulate matter (PM) emissions for Australian road transport by type of vehicle

Financial year	Cars	Light commercial vehicles	Rigid and other trucks	Articulated trucks	Buses	Motorcycles	Total
				(gigagrams)			
1990	10.74	5.28	5.17	3.87	1.41	0.11	26.58
1991	10.53	4.84	4.63	3.78	1.36	0.10	25.23
1992	10.22	5.05	4.45	3.77	1.32	0.10	24.91
1993	10.05	5.19	4.37	3.99	1.29	0.10	24.97
1994	9.85	5.27	4.51	4.02	1.33	0.09	25.07
1995	9.82	5.51	4.75	4.19	1.36	0.09	25.72
1996	9.60	5.59	5.01	4.28	1.37	0.09	25.94
1997	9.33	4.78	5.35	4.35	1.35	0.09	25.25
1998	9.16	4.99	5.34	4.34	1.35	0.08	25.27
1999	9.05	4.83	5.20	4.24	1.33	0.08	24.73
2000	9.11	4.59	5.11	4.12	1.31	0.08	24.32
2001	8.87	4.63	4.87	3.86	1.32	0.08	23.62
2002	8.94	4.86	4.87	3.74	1.27	0.08	23.76
2003	9.01	4.84	4.79	3.56	1.24	0.09	23.52
2004	9.25	4.92	4.61	3.36	1.20	0.09	23.43
2005	9.15	4.87	4.46	3.13	1.13	0.10	22.83
2006	8.91	4.75	4.21	2.92	1.03	0.10	21.92
2007	8.88	4.68	4.07	2.77	0.98	0.11	21.49
Forecasts							
2008	8.83	4.63	3.87	2.61	0.93	0.11	20.98
2009	8.91	4.61	3.67	2.49	0.88	0.11	20.68
2010	8.91	4.63	3.47	2.40	0.83	0.12	20.36
2011	8.76	4.67	3.27	2.33	0.78	0.12	19.92
2012	8.56	4.73	3.08	2.27	0.73	0.12	19.48
2013	8.35	4.78	2.91	2.22	0.68	0.12	19.06
2014	8.16	4.82	2.79	2.19	0.63	0.12	18.70
2015	8.00	4.87	2.68	2.16	0.59	0.13	18.43
2016	7.84	4.93	2.60	2.14	0.56	0.13	18.20
2017	7.75	4.97	2.51	2.16	0.53	0.13	18.05
2018	7.68	5.02	2.44	2.20	0.50	0.13	17.97
2019	7.64	5.05	2.40	2.25	0.49	0.14	17.97
2020	7.58	5.12	2.37	2.33	0.48	0.14	18.02

Note: Energy supply emissions are not included.
Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A19 Base case projections of particulate matter (PM) emissions for Australian transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams)		
1990	26.61	0.99	3.45	2.38	33.43
1991	25.26	0.98	2.81	2.42	31.47
1992	24.94	0.96	2.74	2.42	31.06
1993	25.00	0.94	2.27	2.42	30.64
1994	25.10	1.01	1.87	2.43	30.41
1995	25.75	0.99	2.67	2.46	31.87
1996	25.97	0.96	2.76	2.48	32.17
1997	25.28	0.98	2.61	2.49	31.35
1998	25.30	0.99	2.01	2.44	30.75
1999	24.76	1.02	1.51	2.42	29.70
2000	24.35	1.05	1.65	2.42	29.48
2001	23.66	1.03	1.47	2.45	28.61
2002	23.80	1.08	1.39	2.40	28.66
2003	23.55	1.11	1.35	2.37	28.38
2004	23.47	1.19	1.44	2.37	28.47
2005	22.87	1.28	1.50	2.38	28.03
2006	21.96	1.32	1.61	2.41	27.29
2007	21.53	1.36	1.70	2.43	27.02
Forecasts					
2008	21.02	1.43	1.76	2.43	26.64
2009	20.72	1.49	1.82	2.43	26.46
2010	20.40	1.54	1.89	2.43	26.25
2011	19.96	1.58	1.93	2.43	25.90
2012	19.52	1.61	1.92	2.43	25.48
2013	19.10	1.64	1.92	2.43	25.09
2014	18.74	1.68	1.92	2.42	24.77
2015	18.47	1.71	1.92	2.42	24.52
2016	18.24	1.75	1.92	2.41	24.33
2017	18.09	1.77	1.91	2.41	24.19
2018	18.01	1.80	1.90	2.40	24.11
2019	18.01	1.83	1.89	2.39	24.13
2020	18.06	1.86	1.89	2.39	24.19

Notes: 'Motor vehicles' includes all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy supply emissions are not included (i.e. rail does not include emissions from electricity generation).

Sources: BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A20 Base case projections of crude oil prices

Financial year	*Base case*	*High scenario*	*Low scenario*
	US$ per barrel of crude (constant 2004 dollars)		
1990	30.39	30.39	30.39
1991	36.19	36.19	36.19
1992	27.92	27.92	27.92
1993	27.25	27.25	27.25
1994	21.34	21.34	21.34
1995	24.17	24.17	24.17
1996	24.87	24.87	24.87
1997	27.80	27.80	27.80
1998	20.14	20.14	20.14
1999	15.90	15.90	15.90
2000	30.28	30.28	30.28
2001	32.19	32.19	32.19
2002	24.89	24.89	24.89
2003	31.55	31.55	31.55
2004	34.47	34.47	34.47
2005	47.17	47.17	47.17
2006	60.17	60.17	60.17
2007	58.20	59.00	57.80
Forecasts			
2008	59.00	62.27	57.63
2009	55.95	62.41	51.15
2010	55.00	66.68	47.21
2011	54.00	71.14	43.33
2012	52.88	74.97	39.70
2013	50.83	76.67	36.90
2014	49.80	78.83	35.24
2015	49.67	80.65	33.82
2016	49.80	83.17	33.47
2017	50.21	84.37	33.17
2018	50.83	86.40	33.21
2019	51.35	88.18	33.10
2020	51.77	90.24	33.11

Note: US Refiner's Acquisition Cost values from AEO2007 data (EIA 2007a) have been adjusted to real West Texas Intermediate (WTI) financial year values.

Sources: BTRE (2006a, 2007a), EIA (2007a, 2007b, 2006) and BITRE estimates.

Table A21 Base case projections of total road vehicle energy consumption by fuel type, end use, 1990–2020

Financial year	Total petrol	ADO	LPG	Natural gas	Biofuels	Total
			(petajoules)			
1990	577.9	197.8	23.1	0.11	0.00	798.9
1991	564.1	191.7	28.0	0.24	0.00	784.0
1992	566.5	194.5	32.5	0.37	0.01	793.9
1993	576.6	202.1	38.1	0.45	0.02	817.3
1994	583.1	209.8	44.7	0.54	0.05	838.1
1995	590.6	223.2	54.5	0.65	0.12	869.1
1996	594.3	235.3	58.0	0.74	0.24	888.6
1997	593.7	243.6	62.8	0.79	0.37	901.2
1998	593.7	256.3	65.9	0.88	0.50	917.3
1999	602.6	264.5	66.1	0.96	0.70	934.9
2000	610.0	273.8	67.0	0.99	1.04	952.9
2001	603.0	276.0	64.5	1.04	1.59	946.2
2002	612.8	290.6	66.8	1.24	2.09	973.4
2003	627.4	303.6	67.3	1.33	1.81	1 001.5
2004	650.8	318.6	65.9	1.38	0.70	1 037.3
2005	650.5	334.2	60.8	1.44	0.67	1 047.6
2006	629.2	347.7	71.3	1.57	1.51	1 051.2
2007	637.5	363.9	68.8	1.71	3.44	1 075.4
Forecasts						
2008	643.1	371.4	72.0	1.85	4.62	1 093.0
2009	657.6	381.1	75.1	2.00	5.79	1 121.6
2010	664.8	392.4	78.3	2.16	6.97	1 144.6
2011	668.6	403.9	81.4	2.34	8.14	1 164.3
2012	670.4	415.6	84.6	2.53	9.32	1 182.4
2013	672.0	427.5	87.7	2.75	9.65	1 199.5
2014	673.8	439.3	90.8	2.98	9.98	1 216.9
2015	674.9	452.2	94.0	3.25	10.31	1 234.7
2016	675.2	466.2	95.8	3.54	10.46	1 251.2
2017	675.1	480.5	97.7	3.87	10.62	1 267.8
2018	674.1	495.3	99.5	4.23	10.77	1 283.9
2019	674.0	511.0	101.3	4.66	10.93	1 301.9
2020	670.9	528.2	102.9	5.14	11.24	1 318.4

Notes: Total petrol—all automotive gasoline use. ADO—automotive diesel oil. LPG—liquefied petroleum gas. Biofuel sales consist primarily of ethanol (typically in a 10 per cent ethanol-petrol blend, E10), and biodiesel (used both blended and unblended).

Petajoules = 10^{15} Joules.

Sources: ABARE (2007a), BTRE (2006a, 2003a, 2003c, 2002a), DITR (2007a) and BITRE estimates.

Table A22 Base case projections of national motor vehicle energy consumption by type of vehicle, end use, 1990–2020

Financial year	Cars	Light commercial vehicles	Rigid and other trucks	Articulated trucks	Buses	Motorcycles	Total
				(petajoules)			
1990	509.8	113.5	73.2	80.8	17.9	3.6	798.9
1991	509.2	109.2	65.5	79.6	17.3	3.2	784.0
1992	518.1	112.3	63.1	80.3	16.9	3.2	793.9
1993	533.6	115.3	62.2	86.3	16.7	3.2	817.3
1994	546.4	118.2	64.4	88.8	17.2	3.2	838.1
1995	560.6	124.4	67.8	95.6	17.5	3.1	869.1
1996	567.0	128.4	71.8	100.6	17.8	3.0	888.6
1997	569.4	128.9	77.3	105.0	17.7	3.0	901.2
1998	573.0	135.6	78.4	109.5	17.9	2.9	917.3
1999	583.3	139.4	77.9	113.4	18.1	2.8	934.9
2000	593.0	142.5	79.2	117.1	18.3	2.8	952.9
2001	586.1	144.6	77.5	116.2	18.9	2.9	946.2
2002	599.7	151.2	80.4	120.3	18.9	2.9	973.4
2003	614.9	156.4	83.3	124.5	19.3	3.0	1 001.5
2004	637.9	162.2	85.0	129.2	19.7	3.3	1 037.3
2005	639.2	163.7	88.2	133.5	19.7	3.4	1 047.6
2006	633.1	165.8	92.3	136.8	19.6	3.6	1 051.2
2007	643.1	169.0	96.1	143.4	20.0	3.8	1 075.4
Forecasts							
2008	650.9	173.0	98.1	146.7	20.3	3.9	1 093.0
2009	668.4	177.1	100.3	151.2	20.6	4.0	1 121.6
2010	678.4	182.4	102.0	156.7	21.0	4.1	1 144.6
2011	685.2	187.9	103.3	162.4	21.3	4.2	1 164.3
2012	690.5	193.8	103.9	168.3	21.7	4.3	1 182.4
2013	695.4	199.3	104.4	174.0	22.1	4.3	1 199.5
2014	700.5	204.8	105.4	179.2	22.5	4.4	1 216.9
2015	706.0	210.4	106.4	184.4	23.0	4.5	1 234.7
2016	709.9	216.1	107.7	189.4	23.5	4.5	1 251.2
2017	713.3	222.3	108.8	194.6	24.1	4.6	1 267.8
2018	716.2	228.6	109.8	200.0	24.6	4.7	1 283.9
2019	720.3	235.1	111.4	205.1	25.2	4.8	1 301.9
2020	722.6	241.9	112.9	210.3	25.9	4.8	1 318.4

Note: Petajoules = 10^{15} Joules.
Sources: ABARE (2007a), BTRE (2007a, 2006a, 2003a, 2003c, 2002a), DITR (2007a) and BITRE estimates.

Table A23 Base case projections of average fuel intensity for all Australian road travel by type of vehicle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*	*Buses*	*Motorcycles*
			(L/100km)			
1990	12.02	13.74	27.73	50.54	31.16	5.90
1991	11.96	13.62	27.71	50.56	31.07	5.80
1992	11.91	13.53	27.68	50.63	30.75	5.80
1993	11.88	13.50	27.71	50.85	30.23	5.80
1994	11.84	13.49	27.72	51.17	29.88	5.80
1995	11.76	13.50	27.82	51.59	29.56	5.80
1996	11.71	13.48	27.94	51.94	29.25	5.80
1997	11.65	13.44	28.01	52.19	28.97	5.80
1998	11.59	13.44	28.07	52.55	28.74	5.80
1999	11.52	13.42	28.15	52.88	28.45	5.80
2000	11.47	13.40	28.15	53.20	28.18	5.75
2001	11.44	13.38	28.18	53.48	27.93	5.70
2002	11.41	13.41	28.20	53.77	27.79	5.75
2003	11.40	13.41	28.16	54.05	27.75	5.85
2004	11.38	13.41	28.08	54.31	27.64	5.85
2005	11.35	13.40	27.99	54.54	27.52	5.80
2006	11.30	13.40	27.87	54.74	27.24	5.80
2007	11.26	13.38	27.76	54.90	27.24	5.75
Forecasts						
2008	11.22	13.35	27.66	55.03	27.11	5.75
2009	11.20	13.31	27.58	55.16	26.99	5.70
2010	11.15	13.27	27.53	55.28	26.97	5.70
2011	11.09	13.21	27.48	55.37	26.89	5.70
2012	11.03	13.19	27.45	55.48	26.84	5.65
2013	10.97	13.14	27.44	55.58	26.82	5.65
2014	10.91	13.09	27.45	55.67	26.82	5.60
2015	10.85	13.03	27.47	55.75	26.87	5.60
2016	10.79	12.98	27.51	55.83	26.93	5.55
2017	10.73	12.93	27.57	55.93	27.10	5.50
2018	10.67	12.89	27.63	56.02	27.19	5.45
2019	10.61	12.86	27.71	56.11	27.31	5.45
2020	10.55	12.83	27.81	56.22	27.44	5.40

Note: Gasoline equivalent fuel intensity for light vehicles and diesel equivalent fuel intensity for heavy vehicles.
Sources: ABS (2006a and earlier), BTRE (2007a, 2006a, 2003a, 2003c, 2002a), DITR (2007a), DTM (1996) and BITRE estimates.

Table A24 Base case projections of average energy intensity for national road freight tasks, by type of vehicle

Financial year	*Light commercial vehicles*	*Rigid and other trucks*	*Articulated trucks*
		(Megajoules per tonne kilometre)	
1990	24.4	3.22	1.28
1991	23.9	3.13	1.27
1992	23.8	3.12	1.27
1993	23.7	3.12	1.27
1994	23.5	3.12	1.24
1995	23.4	3.11	1.23
1996	23.3	3.12	1.22
1997	22.9	3.12	1.21
1998	23.0	3.10	1.19
1999	22.8	3.08	1.17
2000	22.7	3.02	1.13
2001	22.7	2.98	1.09
2002	22.7	2.96	1.07
2003	22.8	2.94	1.06
2004	22.7	2.91	1.04
2005	22.6	2.88	1.04
2006	22.5	2.85	1.02
2007	22.5	2.83	1.01
Forecasts			
2008	22.4	2.81	0.99
2009	22.3	2.78	0.98
2010	22.1	2.76	0.97
2011	22.0	2.74	0.95
2012	21.9	2.73	0.95
2013	21.8	2.71	0.94
2014	21.6	2.70	0.93
2015	21.5	2.69	0.92
2016	21.4	2.68	0.91
2017	21.3	2.67	0.91
2018	21.2	2.67	0.90
2019	21.1	2.66	0.89
2020	21.1	2.66	0.88

Note: Values are calculated using total in-vehicle fuel use and total tonne-km estimates—so are averages across total vehicle activity (even trips while unladen).

Sources: ABS (2006a and earlier), BTE (1999a), BTRE (2006a, 2003a, 2003c, 2002a) and BITRE estimates.

Table A25 Base case projections of rail tasks, 1990–2020

Financial year	Non-urban passenger	Urban passenger heavy rail	Urban passenger light rail	Hire and reward non-bulk freight	Hire and reward bulk freight	Hire and reward total	Ancillary freight
	(billion passenger kilometres)			(billion tonne kilometres)			
1990	2.354	7.182	0.479	19.49	35.36	54.86	33.06
1991	2.364	7.231	0.525	19.17	36.20	55.36	35.76
1992	2.264	7.061	0.499	19.72	37.35	57.07	42.25
1993	2.264	6.853	0.487	21.78	37.92	59.69	41.09
1994	2.207	7.103	0.482	22.65	38.81	61.46	42.76
1995	2.222	7.514	0.498	21.69	40.71	62.40	43.79
1996	2.247	7.649	0.518	20.90	42.58	63.48	46.77
1997	2.180	7.866	0.519	22.25	47.97	70.22	49.40
1998	2.120	7.871	0.502	25.51	48.93	74.44	51.15
1999	2.148	8.033	0.530	26.33	50.08	76.41	51.55
2000	2.376	8.341	0.560	27.39	57.17	84.57	49.00
2001	2.430	8.910	0.568	27.95	57.46	85.41	51.50
2002	2.444	8.985	0.576	29.60	62.90	92.50	57.96
2003	2.328	8.962	0.570	31.30	67.19	98.49	64.00
2004	2.300	9.225	0.570	35.80	71.05	106.85	68.48
2005	2.200	9.399	0.575	39.28	72.24	111.52	77.73
2006	2.233	9.662	0.587	41.23	74.37	115.60	80.42
2007	2.273	9.895	0.606	43.21	73.49	116.70	90.18
Forecasts							
2008	2.323	10.149	0.617	45.58	77.68	123.26	96.69
2009	2.356	10.361	0.629	47.49	80.27	127.76	104.96
2010	2.388	10.563	0.641	48.92	82.63	131.55	114.49
2011	2.418	10.761	0.653	50.29	84.81	135.11	122.45
2012	2.451	10.961	0.666	51.54	86.77	138.30	126.66
2013	2.485	11.164	0.680	52.79	88.86	141.64	131.60
2014	2.522	11.370	0.694	54.05	91.94	145.99	137.26
2015	2.560	11.571	0.709	55.36	94.34	149.70	143.29
2016	2.597	11.772	0.724	56.62	96.70	153.32	149.03
2017	2.634	11.980	0.739	57.87	99.10	156.97	154.07
2018	2.670	12.179	0.754	59.12	101.54	160.66	158.83
2019	2.708	12.387	0.770	60.38	104.06	164.44	164.02
2020	2.749	12.605	0.786	61.66	106.74	168.40	169.62

Note: Total rail tasks—electric and non-electric railways.
Sources: ACG (2007), BTRE (2007e, 2006a, 2002a), Cosgrove & Gargett (2007, 1992) and BITRE estimates.

Table A26 Base case projections of total energy consumption (end use) by Australian civil transport by mode, 1990–2020

Financial year	*Motor vehicles*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(petajoules)		
1990	799.8	24.8	31.7	40.8	897.1
1991	784.9	24.7	27.5	50.7	887.6
1992	794.8	24.0	28.2	55.0	902.0
1993	818.2	23.6	25.6	57.8	925.2
1994	839.1	25.5	23.8	61.1	949.6
1995	870.1	24.8	30.7	72.0	997.7
1996	889.6	24.1	32.5	79.0	1 025.2
1997	902.3	24.6	32.3	84.4	1 043.5
1998	918.4	25.0	28.2	76.5	1 048.1
1999	936.0	25.7	24.1	73.7	1 059.5
2000	954.1	26.6	25.1	77.0	1 082.9
2001	947.3	26.2	23.2	85.8	1 082.5
2002	974.6	27.4	23.5	77.0	1 102.5
2003	1 002.7	28.1	23.6	73.4	1 127.8
2004	1 038.7	30.2	25.1	76.8	1 170.8
2005	1 049.0	32.4	27.8	81.7	1 191.0
2006	1 052.6	33.5	27.3	90.7	1 204.0
2007	1 076.8	34.6	28.4	98.8	1 238.6
Forecasts					
2008	1 094.4	36.4	29.3	101.8	1 261.8
2009	1 123.0	37.9	30.1	104.9	1 296.0
2010	1 146.0	39.2	31.0	108.2	1 324.4
2011	1 165.8	40.4	31.7	111.3	1 349.1
2012	1 183.9	41.2	31.8	113.8	1 370.7
2013	1 201.0	42.0	32.0	116.1	1 391.1
2014	1 218.4	43.0	32.2	118.3	1 411.9
2015	1 236.2	43.9	32.5	120.2	1 432.9
2016	1 252.7	44.8	32.7	121.8	1 452.0
2017	1 269.3	45.6	32.8	123.4	1 471.1
2018	1 285.4	46.3	32.9	124.9	1 489.6
2019	1 303.5	47.1	33.0	126.4	1 510.0
2020	1 320.0	47.9	33.1	128.0	1 529.0

Notes: Estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways).

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy use due to military transport is excluded.

Petajoules = 10^{15} Joules.

Sources: ABARE (2007a), ACG (2007, 2005), BTRE (2006a, 2003a, 2003c, 2002a), DITR (2007a) and BITRE estimates.

Table A27 Base case projections of maritime sector tasks, 1990–2020

Financial year	*Estimated passenger task (all domestic marine)*	*Estimated bulk freight, coastal shipping*	*Estimated non-bulk freight, coastal shipping*	*Total freight, coastal shipping*
	(billion passenger kilometres)	*(billion tonne kilometres)*		
1990	0.209	91.3	2.86	94.2
1991	0.211	90.8	2.99	93.8
1992	0.213	93.3	3.08	96.4
1993	0.215	92.8	3.23	96.0
1994	0.218	94.8	3.44	98.3
1995	0.230	108.5	3.63	112.1
1996	0.239	104.5	3.70	108.2
1997	0.251	108.9	3.69	112.6
1998	0.252	112.6	4.48	117.0
1999	0.257	104.4	4.49	108.8
2000	0.264	103.0	5.90	108.9
2001	0.286	97.4	7.12	104.5
2002	0.286	104.1	6.35	110.4
2003	0.347	107.2	7.56	114.8
2004	0.378	108.2	8.71	117.0
2005	0.385	106.7	7.36	114.0
2006	0.393	115.3	6.74	122.0
2007	0.401	122.9	7.50	130.4
Forecasts				
2008	0.408	128.7	7.66	136.4
2009	0.415	134.4	7.80	142.2
2010	0.421	140.8	7.94	148.8
2011	0.427	145.7	8.08	153.7
2012	0.433	147.0	8.21	155.2
2013	0.439	148.8	8.34	157.1
2014	0.445	151.2	8.48	159.7
2015	0.452	153.4	8.61	162.0
2016	0.458	155.3	8.74	164.1
2017	0.463	156.6	8.87	165.4
2018	0.469	157.5	9.00	166.5
2019	0.475	158.7	9.13	167.8
2020	0.481	159.9	9.26	169.2

Sources: ACG (2007, 2005), BTRE (2007c, 2006a, 2003a) and BITRE estimates.

Table A28 BTRE Base Case 2006 projections: comparison table for current forecast years, emissions from Australian domestic transport energy end use by mode, 2007–2020

Financial year	*Road*	*Rail (non-electric)*	*Maritime*	*Aviation*	*Total*
			(gigagrams of direct CO_2 equivalent)		
2007	75 772	2 165	2 063	6 361	86 360
2008	77 471	2 209	2 069	6 599	88 348
2009	79 180	2 253	2 073	6 828	90 333
2010	80 737	2 287	2 077	7 065	92 165
2011	82 187	2 317	2 079	7 211	93 794
2012	83 265	2 353	2 084	7 408	95 111
2013	84 214	2 385	2 090	7 589	96 279
2014	85 102	2 417	2 096	7 664	97 279
2015	85 936	2 448	2 103	7 813	98 299
2016	86 716	2 477	2 110	7 945	99 249
2017	87 439	2 508	2 118	8 073	100 139
2018	88 088	2 539	2 127	8 201	100 956
2019	88 747	2 570	2 136	8 327	101 781
2020	89 370	2 602	2 146	8 452	102 570

Notes: Emission estimates are for direct greenhouse gas emissions only—carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using AGO-preferred values for the Global Warming Potentials (of 21 for methane and 310 for nitrous oxide).

'Motor vehicles' include all road vehicles plus off-road recreational vehicles. 'Aviation' includes emissions from general aviation as well as airlines. 'Maritime' includes emissions from small pleasure craft and ferries as well as coastal shipping.

Energy use due to military transport is excluded.

Emission estimates relate to energy end use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways).

Sources: BTRE unpublished estimates for AGO (August 2006)—based on BTRE (2002a, 2003a, 2003c, 2006a).

Table A29 Assumed energy conversion factors and combustion characteristics for transport fuels, Australian averages

Fuel type	*CO_2 emissions (g/MJ)*	*Liquid energy density (MJ/L)*	*Proportional oxidation factor*
Petrol	67.4	34.2	0.990
ADO	69.9	38.6	0.990
LPG	60.2	25.7	0.990
Natural Gas	51.4	25.0	0.995
Ethanol	63.0	23.4	0.990
Biodiesel	69.9	34.7	0.990
Avgas	67.0	33.1	0.990
Avtur	69.6	36.8	0.990
IDF	69.9	39.6	0.990
Fuel oil	73.6	40.8	0.990
Coal (black)	90.0	na	0.985

na not applicable

Notes: IDF—Industrial diesel fuel

MJ—megajoules, million joules

Emission values based on the assumption of full carbon combustion (apart from the portion assumed to remain unburnt, and typically released as fine solids) for all transport fuels.

Sources: NGGIC (2007, 2006a, 2006b) and BITRE estimates.

Table A30 Projections of total greenhouse gas (carbon dioxide equivalent) emissions for Australian road transport by type of vehicle, over the full fuel cycle, 1990–2020

Financial year	*Cars*	*Light commercial vehicles*	*Rigid trucks*	*Articulated trucks*	*Buses*	*Motorcycles*	*Total Road*
			(gigagrams of CO_2 equivalent)				
1990	47 980	10 219	6 389	6 867	1 558	363	73 376
1991	47 784	9 834	5 705	6 763	1 506	322	71 914
1992	48 559	10 104	5 488	6 819	1 469	321	72 759
1993	49 878	10 361	5 406	7 322	1 451	321	74 739
1994	50 878	10 595	5 585	7 534	1 498	316	76 405
1995	52 027	11 146	5 874	8 097	1 523	312	78 980
1996	52 402	11 494	6 201	8 503	1 543	302	80 444
1997	52 413	11 539	6 659	8 861	1 532	300	81 304
1998	52 452	12 084	6 741	9 222	1 551	289	82 338
1999	53 066	12 378	6 686	9 522	1 564	277	83 493
2000	53 619	12 612	6 779	9 814	1 571	279	84 674
2001	52 649	12 738	6 613	9 718	1 614	285	83 617
2002	53 539	13 259	6 839	10 038	1 601	289	85 565
2003	54 598	13 662	7 086	10 389	1 649	301	87 686
2004	56 372	14 121	7 222	10 761	1 676	327	90 479
2005	56 135	14 191	7 472	11 095	1 670	339	90 902
2006	55 173	14 310	7 802	11 352	1 648	354	90 639
2007	55 670	14 523	8 103	11 872	1 671	380	92 219
Forecasts							
2008	56 005	14 825	8 244	12 120	1 682	390	93 264
2009	57 181	15 121	8 401	12 467	1 692	397	95 259
2010	57 722	15 511	8 523	12 895	1 709	406	96 765
2011	58 011	15 917	8 605	13 343	1 722	414	98 013
2012	58 179	16 356	8 635	13 801	1 737	420	99 129
2013	58 352	16 763	8 665	14 252	1 759	429	100 220
2014	58 561	17 173	8 734	14 669	1 783	435	101 355
2015	58 820	17 586	8 803	15 079	1 812	444	102 545
2016	58 978	18 010	8 900	15 480	1 847	450	103 663
2017	59 104	18 477	8 980	15 893	1 890	456	104 799
2018	59 246	18 957	9 055	16 321	1 928	461	105 969
2019	59 520	19 452	9 180	16 732	1 970	470	107 325
2020	59 651	19 975	9 291	17 146	2 012	476	108 551

Notes: Values here are total greenhouse gas emissions (direct and indirect radiative forcing effects)—for direct gases: carbon dioxide, methane and nitrous oxide; and indirect gases (ozone precursors): carbon monoxide, nitrogen dioxide and volatile organic compounds); converted into total CO_2 equivalent figures using BITRE approximate valuations of average Global Warming Potentials for indirect warming effects.

Emission estimates relate to full fuel cycle energy use (i.e. include upstream energy use for transport fuel supply and processing, but exclude CO_2 released from the in-vehicle combustion of biofuels).

Emissions due to military vehicles are excluded.

Sources: BTCE (1996a, 1995a), BTRE (2007a, 2006a, 2003c, 2002a), Fuglestvedt et al. (2001), IPCC (1990, 2001, 2007a) and BITRE estimates.

Table A31 Projections of total greenhouse gas (carbon dioxide equivalent) emissions for Australian domestic civil transport by mode, over the full fuel cycle, 1990–2020

Financial year	*Motor vehicles*	*Rail (electric and non-electric)*	*Maritime*	*Aviation*	*Total domestic transport*
		(gigagrams of CO_2 equivalent)			
1990	73 464	3 690	3 170	5 358	85 682
1991	72 002	3 665	2 786	6 649	85 103
1992	72 849	3 631	2 867	7 216	86 562
1993	74 832	3 565	2 638	7 583	88 618
1994	76 502	3 714	2 484	8 023	90 723
1995	79 080	3 747	3 132	9 452	95 410
1996	80 547	3 619	3 300	10 371	97 838
1997	81 409	3 764	3 292	11 070	99 535
1998	82 445	3 781	2 923	10 040	99 189
1999	83 604	3 872	2 571	9 666	99 713
2000	84 788	4 037	2 685	10 102	101 611
2001	83 732	4 005	2 511	11 253	101 501
2002	85 684	4 106	2 552	10 087	102 430
2003	87 810	4 172	2 577	9 626	104 185
2004	90 610	4 368	2 751	10 069	107 797
2005	91 035	4 587	3 013	10 711	109 346
2006	90 774	4 720	2 893	11 888	110 275
2007	92 355	4 857	3 005	12 949	113 166
Forecasts					
2008	93 402	5 055	3 086	13 333	114 876
2009	95 399	5 218	3 165	13 749	117 531
2010	96 906	5 363	3 251	14 169	119 690
2011	98 155	5 489	3 311	14 576	121 531
2012	99 272	5 585	3 325	14 906	123 089
2013	100 365	5 682	3 343	15 208	124 598
2014	101 502	5 796	3 369	15 490	126 157
2015	102 693	5 902	3 392	15 745	127 731
2016	103 812	6 002	3 412	15 955	129 182
2017	104 950	6 097	3 425	16 157	130 629
2018	106 121	6 189	3 433	16 355	132 098
2019	107 478	6 285	3 444	16 552	133 759
2020	108 705	6 387	3 457	16 752	135 300

Notes: Values here are total greenhouse gas emissions (direct and indirect radiative forcing effects)—for direct gases: carbon dioxide, methane and nitrous oxide; and indirect gases (ozone precursors): carbon monoxide, nitrogen dioxide and volatile organic compounds); converted into total CO_2 equivalent figures using BITRE approximate valuations of average Global Warming Potentials for indirect warming effects.

Emission estimates relate to full fuel cycle energy use (i.e. include upstream energy use for transport fuel supply and processing, but exclude CO_2 released from the in-vehicle combustion of biofuels).

Emissions due to military transport are excluded.

Sources: BTCE (1996a, 1995a), BTRE (2007a, 2006a, 2003c, 2002a), Fuglestvedt et al. (2001), IPCC (1990, 2001, 2007a) and BITRE estimates.

Table A32 Projections of total greenhouse gas (carbon dioxide equivalent) emissions for the Australian aviation and shipping sectors, including civil international transport, full fuel cycle, 1990–2020

Financial year	*Maritime (domestic and international)*	*Aviation (domestic and international)*
	(gigagrams of CO_2 equivalent)	
1990	16 194	15 553
1991	17 018	17 366
1992	17 937	18 379
1993	18 017	19 617
1994	18 866	20 316
1995	21 008	22 918
1996	20 408	24 842
1997	21 262	26 292
1998	20 101	25 891
1999	19 738	25 104
2000	20 149	26 328
2001	19 807	27 804
2002	18 376	25 229
2003	17 937	24 595
2004	18 654	26 539
2005	19 896	29 448
2006	19 605	30 613
2007	19 833	31 947
Forecasts		
2008	20 437	33 034
2009	21 037	34 236
2010	21 757	35 495
2011	22 292	36 764
2012	22 450	37 812
2013	22 651	38 835
2014	23 007	39 954
2015	23 247	41 048
2016	23 460	42 128
2017	23 611	43 172
2018	23 734	44 192
2019	23 877	45 245
2020	24 034	46 343

Notes: Values here are total greenhouse gas emissions (direct and indirect radiative forcing effects)—for direct gases: carbon dioxide, methane and nitrous oxide; and indirect gases (ozone precursors): carbon monoxide, nitrogen dioxide and volatile organic compounds); converted into total CO_2 equivalent figures using BITRE approximate valuations of average Global Warming Potentials for indirect warming effects.

Emission estimates relate to full fuel cycle energy use (i.e. include upstream energy use for transport fuel supply and processing)—based on total energy consumption for transport within Australia, and half of energy use due to international transport to and from Australia.

Emissions due to military transport are excluded.

Sources: BTCE (1996a, 1995a), BTRE (2007a, 2006a, 2003c, 2002a), Fuglestvedt et al. (2001), IPCC (1990, 2001, 2007a) and BITRE estimates.

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Abbreviations

4WD	Four-wheel drive
AAA	Australian Automobile Association
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AGO	Australian Greenhouse Office
AGPS	Australian Government Publishing Service
ACG	Apelbaum Consulting Group
ADO	automotive diesel oil
ADRs	Australian Design Rules
AEO	Annual Energy Outlook
AIP	Australian Institute of Petroleum
ANZSIC	Australian and New Zealand Standard Industrial Classification
ATW	All Terrain Wagon
Avgas	aviation gasoline
Avtur	aviation turbine fuel
BAU	business-as-usual
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
BTR	Bureau of Tourism Research
BTRE	Bureau of Transport and Regional Economics
CH_4	methane
CFC	chlorofluorocarbon
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 equiv	carbon dioxide equivalent
CPRS	Carbon Pollution Reduction Scheme

CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTL	coal-to-liquids
DCC	Department of Climate Change
DISR	Department of Industry, Science and Resources
DITR	Department of Industry, Tourism and Resources
DOTARS	Department of Transport and Regional Services
DPIE	Department of Primary Industries and Energy
DTM	Dynamic Transport Management
EIA	US Energy Information Administration
ES	Executive Summary
ESAA	Electricity Supply Association of Australia Limited
ESMVI	Environmental Strategy for the Motor Vehicle Industry
EWF	Emission-Weighting Factor
FES	Fuel and Electricity Survey
FFC	full fuel cycle
FORS	Federal Office of Road Safety
FT	Fischer-Tropsch Process
GDP	Gross Domestic Product
Gg	Gigagrams, 10^9 grams (equivalent to thousand tonnes).
GTL	gas-to-liquids
GWP	Global Warming Potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbons
IDF	Industrial Diesel Fuel
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
L/100km	litres consumed per 100 kilometres travelled
LCV	light commercial vehicle
LPG	liquefied petroleum gas
MJ	Megajoules, million Joules
MVC	Motor Vehicle Census

MVEm	Motor Vehicle Emission modelling suite
NAFC	National Average Fuel Consumption
NG	natural gas
NGGI	National Greenhouse Gas Inventory
NGGIC	National Greenhouse Gas Inventory Committee
NGS	National Greenhouse Strategy
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NO_x	nitrogen oxides (primarily NO and NO_2)
NPI	National Pollutant Inventory
PAHs	poly-cyclic hydrocarbons
PFC	perfluorocarbons
PJ	Petajoules, 10^{15} Joules
PKM	passenger kilometres
PM	particulate matter
RET	Department of Resources, Energy and Tourism
RF	Radiative Forcing
SKM	seat kilometres
SMVU	Survey of Motor Vehicle Use
SO_x	sulphur oxides (primarily SO_2 and SO_3)
TKM	tonne kilometres
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VKT	vehicle kilometres travelled
VOC	volatile organic compound
VTPI	Victoria Transport Policy Institute
WTI	West Texas Intermediate