Australian Government

Department of Infrastructure,
Transport, Regional Development
and Local Government
Bureau of Infrastructure, Transport and Regional Economics

CSIRO

Modelling the Road Transport Sector

Appendix to

Australia's Low Pollution Future
The Economics of Climate Change Mitigation

Prepared by BITRE and CSIRO, for Treasury

October 2008

FOREWORD

This appendix was prepared by BITRE and CSIRO, in discussion with Treasury, to provide additional information on the road transport sector modelling carried out jointly by the two agencies in support of Treasury's broader modelling of the introduction of emissions trading in Australia.

Road vehicles currently account for around 85 per cent of the total transport sector emissions. BITRE and CSIRO were engaged by Treasury to provide detailed modelling of the road transport sector to more adequately account for consumers' vehicle and fuel choices from a diverse range of potential technologies, such as hybrid and electric vehicle technologies and biofuels. The greater level of detail that BITRE and CSIRO modelling was able to apply to the emissions trading scenarios ensured that transport activity levels were based on the most important drivers, and a wider range of potential abatement opportunities were able to be explored.

The research used existing models that had been developed and applied over several years. BITRE's fleet-based transport activity models were used to forecast passenger road transport, independently from the Treasury and CSIRO models. The results from BITRE's analysis were used to calibrate and cross-check the macroeconomic models and CSIRO's Energy Sector Model (ESM). The ESM was used to project vehicle technology uptake, fuel use and greenhouse gas emissions. BITRE also played a role in advising CSIRO with this modelling.

The focus of this appendix is road transport. Aviation, rail and shipping sectors were modelled entirely within the general equilibrium model, and discussion of those sectors can be found in Treasury's main report.

The analysis described in this appendix was undertaken by David Cosgrove, David Gargett, William Lu and Jack McAuley of BITRE, and Paul Graham of CSIRO.

CONTENTS

1 INTRODUCTION

The Government has adopted a long term greenhouse gas emission reduction target of 60 per cent below 2000 levels by 2050. The Government's intention is to introduce a Carbon Pollution Reduction Scheme (CPRS) as the primary mechanism to achieve these emission reductions. The Treasury has conducted modelling of the economy-wide effects to 2050 of such a scheme.

The modelling comprised both general equilibrium modelling and bottom-up modelling. The Bureau of Infrastructure, Transport and Regional Economics (BITRE) contributed to this joint modelling effort with bottom-up modelling of the road transport sector using its own transport demand models, and CSIRO assisted with modelling of vehicle technology, fuel use and emissions with their Energy Sector Model (ESM).

As well as the reference scenario, four mitigation scenarios were modelled. Two scenarios – *CPRS -5* and *CPRS -15* – examine the potential costs of the Government's proposed Carbon Pollution Reduction Scheme and long-term target to reduce Australia's emissions by 60 per cent below 2000 levels by 2050. Two further scenarios – *Garnaut -10* and *Garnaut -25* – were developed jointly with the Garnaut Climate Change Review, and were a key input to the Review's independent modelling of the economic impacts of climate change (Garnaut 2008).

The scenarios are described in detail in the main report. From the perspective of the BITRE and CSIRO bottom-up modelling, the key aspect of the scenarios are the CO_2e permit prices that have been calculated within the general equilibrium modelling to be consistent with each scenario. These permit prices are imposed on CSIRO's bottom-up model to determine the abatement response. Besides these permit prices, other key scenario parameters are the demand for road transport, the prices of oil and gas, and the rate of improvement in transport technology.

This appendix outlines:

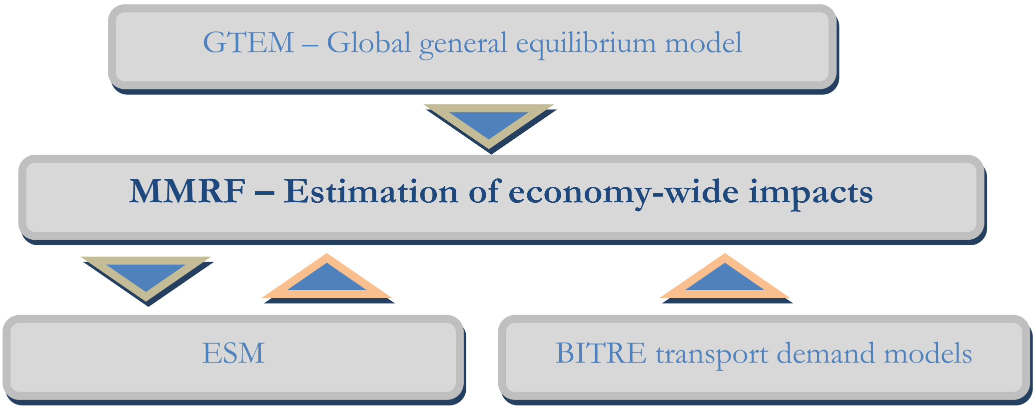
- features of the modelling framework used for the treatment of road transport (Section 2);
- details of BITRE's passenger demand modelling, which informed the transport modelling (Section 3);
- input assumptions to general equilibrium modelling and to CSIRO's bottom-up modelling (Section 4);
- the simulated impact of emissions trading on road transport, including the abatement response of the road transport sector to a price on greenhouse gas emissions and its effects on fuel and transport costs, transport demand, and transport fuel and technology shares (Section 5).

All prices quoted in this report are in 2005 dollars.

2 MODELLING FRAMEWORK

Treasury has employed GTEM, MMRF and CSIRO's partial equilibrium Energy Sector Model (ESM) to obtain a detailed picture of the transport sector (Figure 1). In addition, transport demand modelling from BITRE has been used to inform future passenger road transport activity levels. This modelling framework combines the strengths of each of the models, linking the models in a consistent manner to produce robust results. This is similar to the approach taken to model the electricity sector, where a more detailed bottom-up electricity model has been linked to MMRF and GTEM. Also note that the transport sector demand for electricity has been communicated to MMRF through the ESM and the additional electricity requirement accounted for in the bottom-up electricity modelling.

Figure 1 The Treasury's modelling framework for the road transport sector



GTEM is a global general equilibrium model, more detail about which can be found in Annex A. MMRF is an Australian general equilibrium model and has a more detailed representation of transport industries. The ESM is a 'bottom-up' model that determines the uptake of vehicle and fuel technologies and hence fuel demand. In this case ESM takes demand to be fixed at the level provided by MMRF (with input from BITRE) but normally operates with a price elastic demand function. A small number of iterations are carried out to achieve a reasonable level of consistency. BITRE transport demand models are used to inform MMRF of future transport activity levels.

Road transport in MMRF

For analysing the national economy-wide impact of the CPRS, the Treasury used an enhanced version of the CoPS' MMRF3 model.[1] Changes made to MMRF, including those relating to the transport sector, are detailed in Annex A. Road transport related enhancements to MMRF3 include:

- Improved treatment of fuels and motor vehicles in the model's household demand system;

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[1] The general structure of the MMRF model is described in Adams (2007).

- Incorporation of an explicit multi-product refining industry enabling evaluation of the impact of fuel-specific taxes;
- Detailed treatment of production of renewable fuels; and
- Improvement of the transport emissions accounting mechanism within MMRF.

These enhancements are briefly described below.

A dummy private transport industry with a fuel technology bundle approach

In the standard version of MMRF3, fuels and motor vehicles are specified as substitutes in the household demand system due to the adoption of a stylised Linear Expenditure System. This inconsistency was eliminated by introducing a dummy industry that provides private transport services to households. The dummy industry approach is not new—it has been previously applied in models of this type to deal with household consumption.

The dummy industry approach involves creating a new industry called ‘private transport services’. This industry provides private transport services to households exclusively, using privately-owned motor vehicles as its capital goods, and fuel and other goods as its intermediate inputs. Under this treatment, motor vehicles and fuels are complements.

Within the private transport industry, four types of vehicle technology are recognised: petrol, diesel, hybrid and electric cars. For each of these technologies, price-induced substitution is allowed between some combination of the five major transport fuels (petrol, diesel, LPG, biofuels and electricity).

A multi-product refining industry

In the standard version of MMRF3, each industry produces just one product. For example, the product produced by the *Petrol* industry is *Petroleum* products, which is highly aggregated. This high level of aggregation not only precludes the possibility of a proper measurement of transport emissions within the MMRF model, but also makes it difficult to evaluate the impact of fuel-specific tax policies.

Disaggregation of *Petroleum* products was accomplished by introducing a multi-product refining industry. The main source of data was unpublished ABS statistics showing detailed commodity sales by input-output user at the seven-digit level of the Input–Output Commodity Classification. The modified Petrol industry produces five *Petroleum* products, namely:

- Petroleum for automotive use;
- Diesel for automotive use;
- LPG for automotive use;
- Aviation fuels including aviation gasoline and turbine fuel; and
- Other petroleum products (including kerosene, heating oil, fuel oil, paraffin wax, grease base stock, petroleum jelly and petroleum solvents).

Disaggregation of petroleum products has made it possible to incorporate fuel-specific information such as greenhouse gas penalty duties on petrol and diesel. It also leads to more accurate estimation of transport sector emissions within MMRF.

Detailed treatment of renewable generation

Biofuels have become more important as transport fuels over time. The model now has an explicit representation of biofuels with a multi-product *Grains* industry producing grains and biofuels. This approach not only allows substitution possibilities between biofuel and grains production, but also enables biofuels to be identified as a transport fuel.

Improved transport emissions accounting

The improved version of MMRF adopted the BITRE approach (BTRE 2003a and 2003b) to estimate transport emissions by mode from the MMRF database. Disaggregation of fuels and transport modes and introduction of the 'private transport services' industry have made it possible to estimate transport emissions in a more direct and explicit way. It also provides a useful framework to examine the impacts of greenhouse policies on various sectors of the transport industry.

Accounting for emissions by rail, water and air transport is relatively straightforward though care needs to be taken to exclude road transport that supports these activities. In the case of road transport emissions, there are three emitting categories:

(1) private use of passenger cars, which is represented by the newly created *PrivTranServ* industry;

(2) the 'hire and reward' part of road transport services, which consists of trucking and public transport; and

(3) ancillary transport, which refers to own business transport use by all other industries.

ESM

With CO_2e permit prices, fuel prices and forecast demand for road transport activities from the MMRF as an input, demand for individual fuels and vehicle types is determined using the bottom-up ESM. The ESM is a detailed partial equilibrium model of the Australian energy sector (including transport), co-developed by CSIRO and the Australian Bureau of Agricultural and Resource Economics (ABARE) in 2006. The model has an economic decision-making framework based around the cost of alternative fuels and vehicles, as well as detailed fuel and vehicle technical performance characterisation such as fuel efficiencies and emission factors by transport mode, vehicle type, engine type and age. (It also has an electricity sector component, which was not used in this modelling.) The model estimates uptake of vehicles and fuels on the basis of cost competitiveness, taking into account constraints with regard to the operation of transport markets, current excise and mandated fuel mix legislation, greenhouse gas emission limits or permit prices, existing plant and vehicle stock, and lead times in the availability of new vehicles or plant.

Consumers (both individuals and firms) are assumed to minimise the cost of carrying out a given transport task, through their choices of vehicles and fuels. The mix of vehicle sizes is exogenous in the model, and for this project, the average vehicle size has been assumed to decrease with increases in CO_2e permit prices which increase the cost of fuels. The availability of alternative technologies also depends, exogenously, on the assumed rate of global technological change. The ESM input assumptions come from a variety of sources. These are listed in Table 1. Oil, gas, electricity and CO_2e permit prices together with transport demand are sourced from MMRF, while the other exogenous assumptions are largely based on CSIRO's most recent research in conjunction with other transport industry stakeholders (CSIRO and Future Fuels Forum, 2008; CSIRO, 2008). Detailed assumptions for the ESM can be found in section four of this appendix.

The outputs from the ESM are input back into the MMRF model as part of the iteration process.

Table 1: Inputs and Outputs of the Energy Sector Model (ESM)

ESM Inputs	**ESM Outputs**
Carbon price (from MMRF)	Engine technology uptake by state & vehicle category
Transport demand (from MMRF)	Internal combustion engine
Private transport demand	Hybrid
Road passenger (including busses and taxis)	Plug-in hybrid
Freight demand (including road and rail)	Full electric
Fuel prices (from Treasury's oil and gas price asumptions)	Uptake by Road transport vehicle category
Electricity prices (from MMRF linked with MMA's model)	Passenger (light, medium and heavy), Bus
Fuel efficiency assumptions	Light commercial vehicle (light, medium and heavy)
Technology cost assumptions	Articulated truck and rigid truck
Fuel availability assumptions	Fuel consumption by state and vehicle category
Emission factors	Petrol
Fuel and other vehicle operating costs	Diesel (from oil, coal or gas)
Policy settings (such as ethanol targets)	Liquefied petroleum gas
Share of light, medium and heavy passenger vehicles	Biofuels (biodiesel and ethanol blends)
Share of light, medium and heavy light commercial vehicles	Electricity
	Natural gas and hydrogen
	Greenhouse gas emissions by state, fuel, technology and vehicle category

3 LONG-TERM PASSENGER TRANSPORT DEMAND PROJECTIONS

This section provides a general summary of the approach BITRE has taken to modelling the long-term demand for road passenger transport, used to inform reference scenario passenger transport demand in MMRF and ESM.

BITRE's passenger travel demand models determine passenger mode share simultaneously, hence, this section also contains implicit forecasts of air and rail passenger transport. These implied forecasts may differ slightly from Treasury's results, which were derived directly from the MMRF model.

Aggregate road transport generation

A range of factors influence growth in road passenger transport demand, and consequential transport energy consumption and transport emission levels. The main drivers of the historical growth in total Australian passenger travel have tended to be increases in population and increases in per capita daily travel. Increasing per capita daily travel has principally been the result of rising per capita incomes, typically allowing greater choices in residential location, mode choice, trip selection and higher potential travel speeds, as road networks have developed over time.

Demographic effects (including changes to land-use, urban form and density) can also be important, with respect to how much daily travel increases. The tendency for Australian cities to grow ever outwards, as the demand for increasing levels of residential living space has typically led to more and more greenfield developments, has contributed to longer average trip lengths and increased overall passenger travel.

Transport mode choice, furthermore, depends on a whole range of factors – such as perceived safety, comfort or affordability. The desirability of any extra travel will depend on the overall costs of that travel – not only direct expenses like fuel prices or bus fares, but also more generalised costs, such as the cost of time.

For many years, Australia has seen the complex interplay of all these underlying effects lead to steadily increasing levels of personal mobility – particularly in parallel with the wider availability of motor vehicles. As a result, total Australian passenger travel (in terms of passenger-kilometres performed) has grown almost ten-fold over the last 60 years.

BITRE projections of Australian transport activity are essentially derived from forecasts of regional population growth and income levels, allowing for projected trends in fuel prices and other travel expenses (such as fares or vehicle purchase prices), using a variety of aggregate demand and modal competition/substitution models. For some background material on the 'bottom-up' projection processes and methodologies see BTRE (2002), BTRE (2006b) and BTRE (2003c).

For the road passenger transport reference scenario, the key input assumptions for national population growth, aggregate income growth and fuel price levels are outlined in Annex B.

Trend growth and potential 'saturation'

BITRE's short- to medium-term projection models are typically log-linear equations, relating changes in transport demand levels with underlying changes in average income levels or relevant prices (BTRE 2002), fit from historical data. Such regression models have been fit for each of the major Australian transport tasks. Some aggregate tasks projected by these methods are then split into finer modal subdivisions, based on market share competitiveness models (again fit from the historical mode share and generalised travel cost data).

Econometric functions based on constant elasticity values (such as those detailed in BTRE 2002) should remain largely valid over medium term projection periods (say, ten years or so) for most Australian transport tasks (with the exception of transport trends already exhibiting asymptotic behaviour, such as per capita urban passenger travel – see Figure 3). However, over the longer term, most transport demand patterns are likely to begin exhibiting saturating trends (in per capita terms) – for example, per capita urban passenger travel has exhibited a strong saturating trend with respect to household incomes.

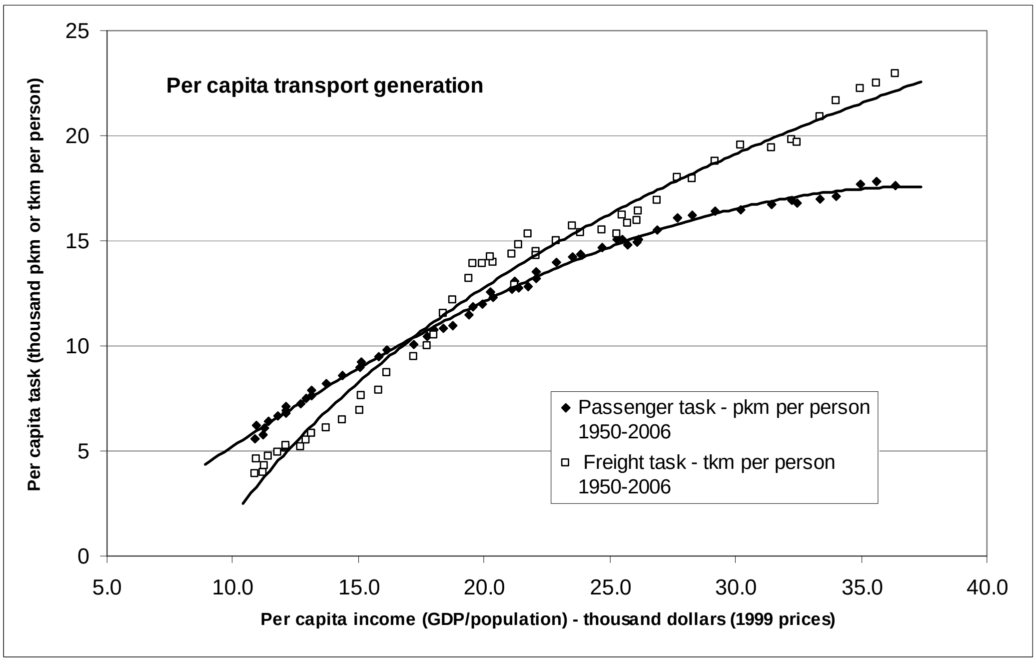
Hence, long-term growth in aggregate transport activity generally entails two components – firstly, making medium term demand forecasts, based primarily on fitted (constant) elasticity values for demand responses to changes in relevant income levels and prices, typically out to about the year 2020; and secondly, continuing those medium term trends out to the 2050 projection endpoint, incorporating any saturation trends identified within the historical data.

Per capita transport trends

A significant relationship underlying BITRE projections of the historical task trends into the future concerns the connection between rising income levels and per capita travel. Figure 2 plots over five decades of per capita passenger and freight movement estimates, for total annual Australian transport tasks, against per capita Australian GDP (as a proxy measure for average household income).

Figure 2 shows that growth in annual passenger-kilometres (pkm) per person has reduced markedly in recent years (right-most points on curve), especially compared with past very high growth in travel (values on the left-most 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 rise. 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 rise further.

Figure 2 Relationship of national per capita transport tasks to per capita income

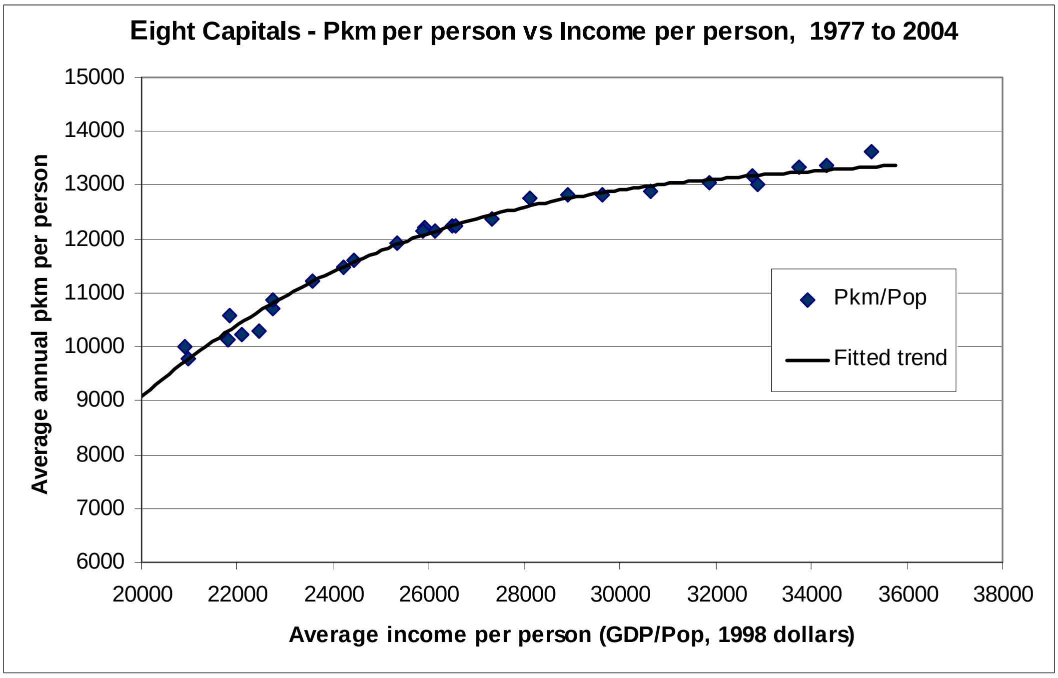


Sources: BTRE (2002, 2006), Cosgrove (2008), Cosgrove and Gargett (2007) and BITRE estimates.

Future increases in total Australian passenger travel are, therefore, likely to be more dependent on the rate of population increase, and less dependent on increases in general prosperity levels.

The saturating relationship between increases in annual passenger kilometres per person and per capita income is even stronger for urban travel than for national travel trends. This relationship, illustrated in Figure 3, implies that saturation in per capita 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. At least until then, increasing household incomes will likely continue to add to per capita travel, and total urban passenger travel will tend to grow at a slightly faster rate than population. Hence, growth in per capita urban travel is thus likely to be lower in the future than for the long-term historical trend.

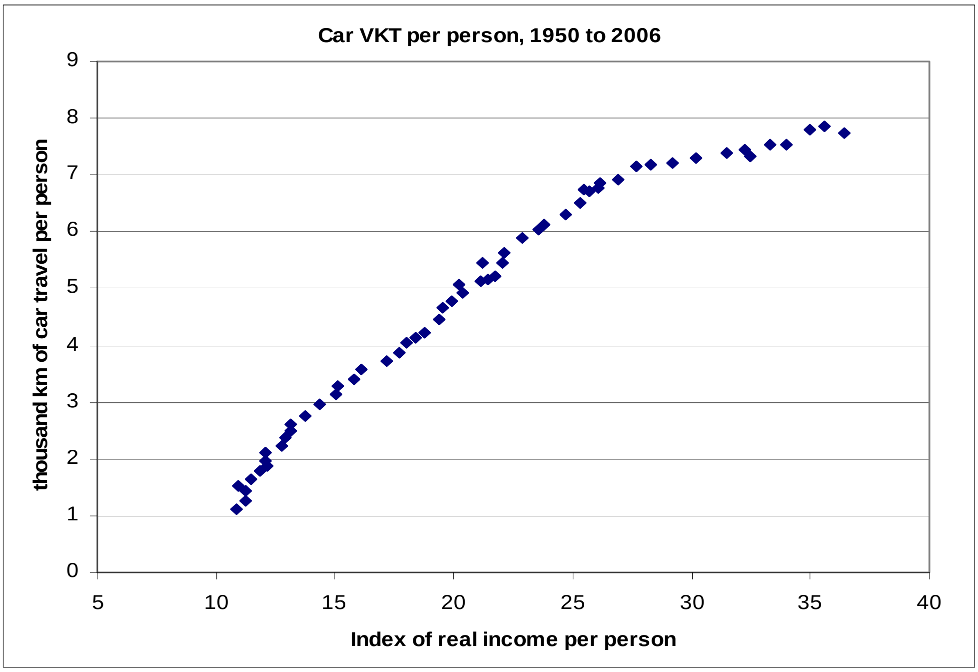
Figure 3 Relationship of metropolitan per capita travel to per capita income



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

Figure 4 shows a longer term view (than Figure 3) of the correspondence between per capita income changes and personal urban travel levels—here restricted to annual metropolitan passenger car use. The flattening off in the per capita trend curve (essentially from the 1980s onwards) is once again evident.

Figure 4 Relationship of metropolitan per capita car travel to per capita income

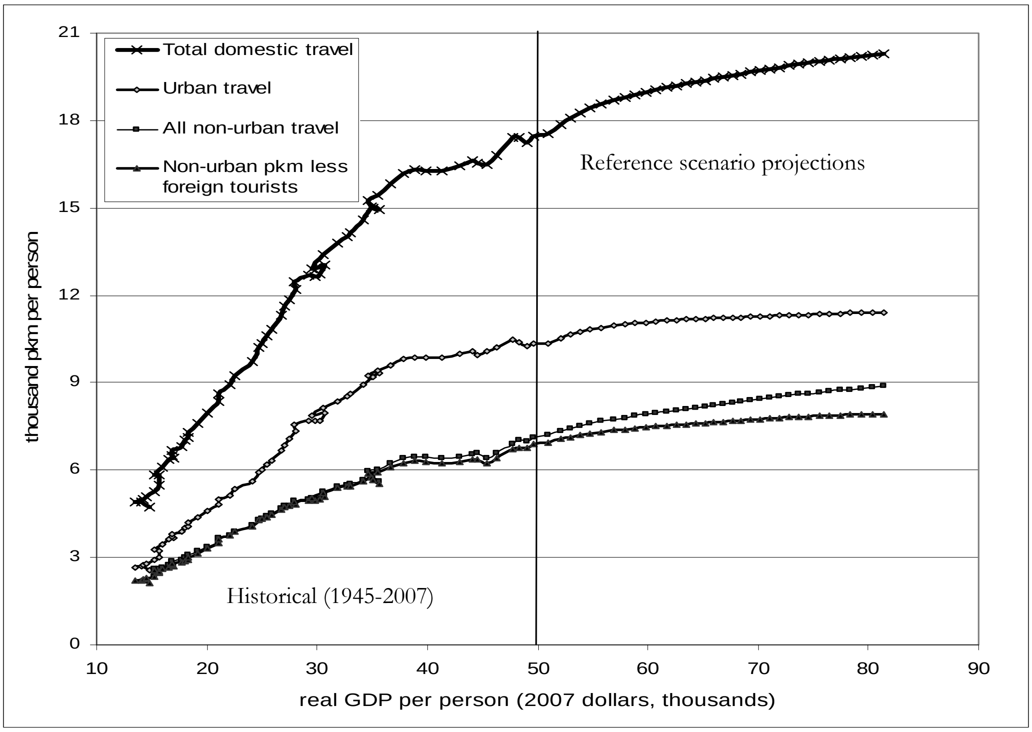


Sources: BTCE (1995, 1996), BTRE (2002, 2006, 2007) and BITRE estimates.

Per capita total passenger transport projection assumptions, 2006–2050

Separate per capita transport trend relationships were used for urban, domestic non-urban and international visitor travel within Australia to derive the total passenger travel projections between 2006 and 2050. The road passenger travel share of projected total passenger travel was derived using separate long-term mode share functions for urban and non-urban travel. Figure 5 shows the long-term trend assumptions for per capita travel, with respect to per capita income growth using the population growth assumptions over the period 2006 to 2050 as in Annex B.

Figure 5 Relationship of per capita Australian travel to per capita income

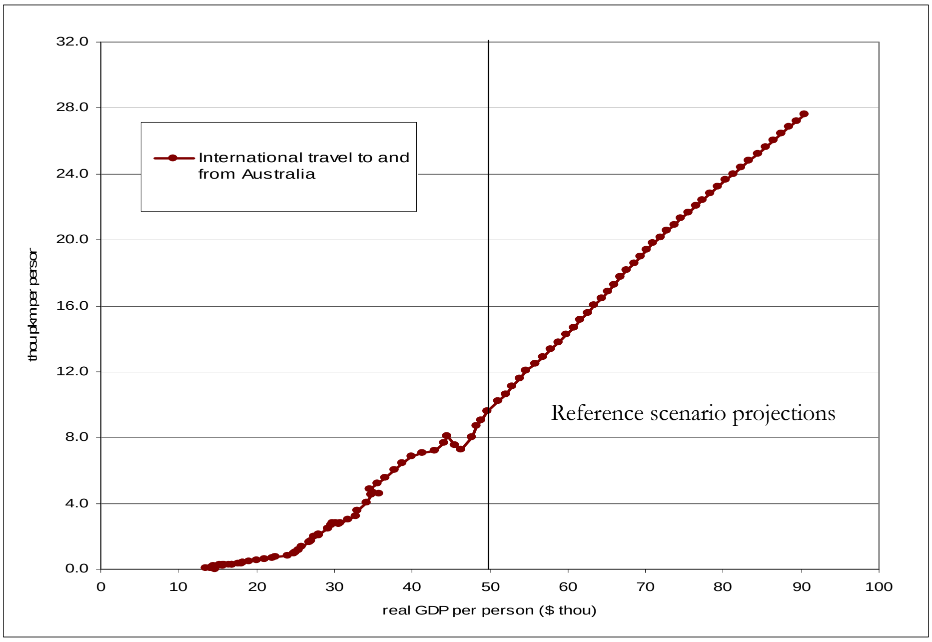


Sources: BITRE (2008), BTRE (2002, 2003, 2006, 2007), Cosgrove (2008) and BITRE estimates.

Foreign tourist travel within Australia is primarily related to total international visitor arrivals, which is largely a function of external economic factors, and is modelled separately to domestic travel. Over the 20 years between 1980 and 2000, growth in foreign visitors to Australia averaged above 9 per cent per annum. This growth rate reflects maturation of the foreign tourist market from a low base, and growth is unlikely to continue at this rate over the long-term. The Tourism Forecast Committee projects that over the 10 years 2006 to 2015, foreign visitor arrivals will grow by around 5 per cent per annum (TRA 2006). For the long-term projections, BITRE assumed foreign visitor arrivals would grow by almost 4 per cent per annum, on average.

The resulting projection trend for international travel (primarily aviation) to and from Australia (i.e. pkm generated per Australian resident) is given in Figure 6.

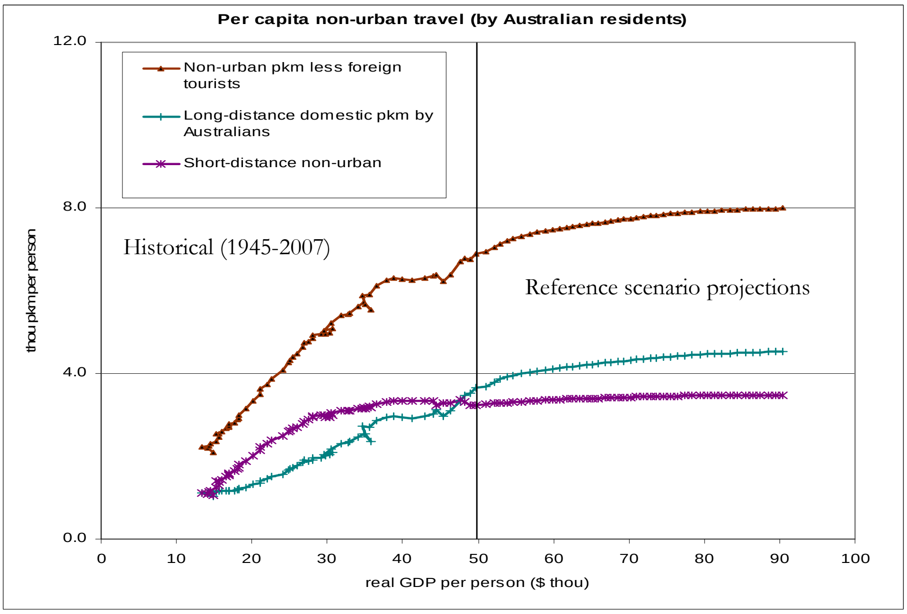
Figure 6 International Travel to and from Australia



Sources: BITRE (2008), BTRE (2002, 2006) and BITRE estimates.

Domestic non-urban travel (by Australians) was subdivided into short-distance travel estimates (such as day-to-day commuting or shopping trips) and long-distance travel estimates (such as holiday trips), and per capita travel trends were estimated separately for each component. Figure 7 shows the resulting curves derived for the long-term trends in these components of non-urban (per capita) passenger movement. Short-distance non-urban trips are assumed to grow very little in per capita terms. Long-distance non-urban travel is projected to exhibit modest growth with respect to rising incomes, principally reflecting increased air travel.

Figure 7 Relationship of non-urban travel to per capita income



Sources: BITRE (2008), BTRE (2002, 2003, 2006), Cosgrove (2008) and BITRE estimates.

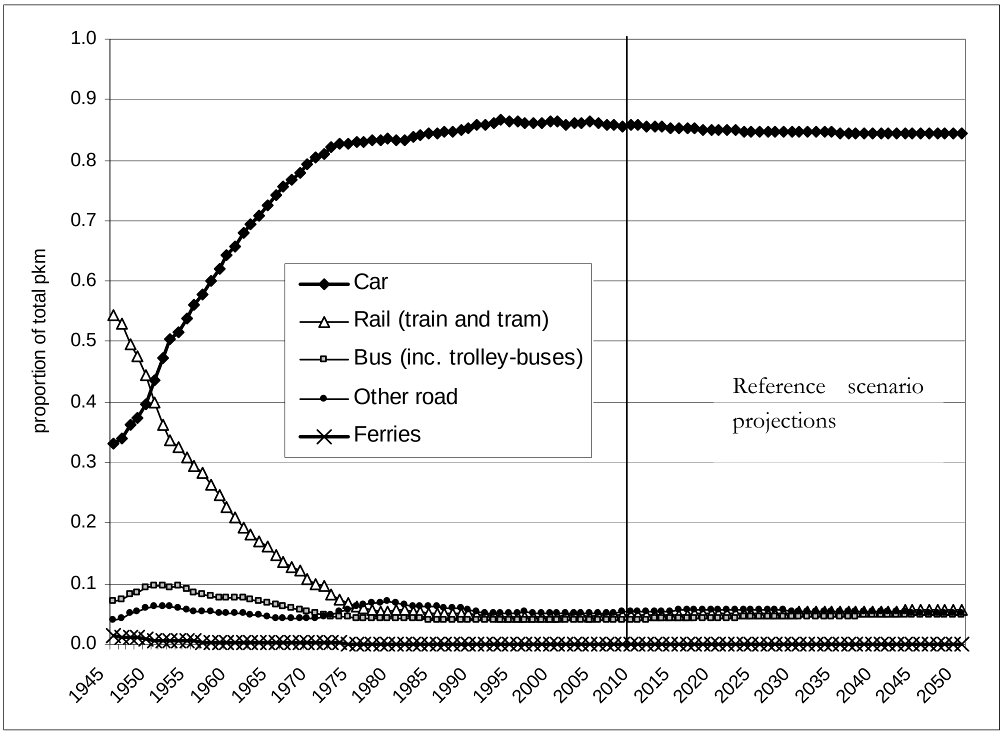
Mode share projections and road passenger travel projections, 2006–2050

For urban transport, private road vehicles currently account for about 90 per cent of the motorised passenger task in Australian cities. The dominance of private motor vehicle travel, in aggregate mode share terms, is clearly demonstrated by the historical trends shown in Figure 8. The modelled reference scenario projections of urban mode share are also given in this chart.

Urban public transport, though generally a major component of peak travel into central business districts, currently represents only about 10 per cent of the total metropolitan passenger task. Moreover, urban public transport's modal share has been remarkably constant since the early 1980s, when the long downward trend in the transit market share, from a level of over 60 per cent just after World War II, finally halted and levelled off. Rail transport accounted for around half of total metropolitan passenger kilometres up until around 1950—but has since fallen to a national average mode share of only about 6 per cent.

Under the reference scenario settings, the aggregate modal share of urban public transport (train, tram and all bus use) is projected to increase—essentially due to future levels of congestion and relatively high petrol prices discouraging some car use – but projected private car travel modal share decreases only slightly over the forecast period.

Figure 8 Modal shares for Australian urban passenger travel

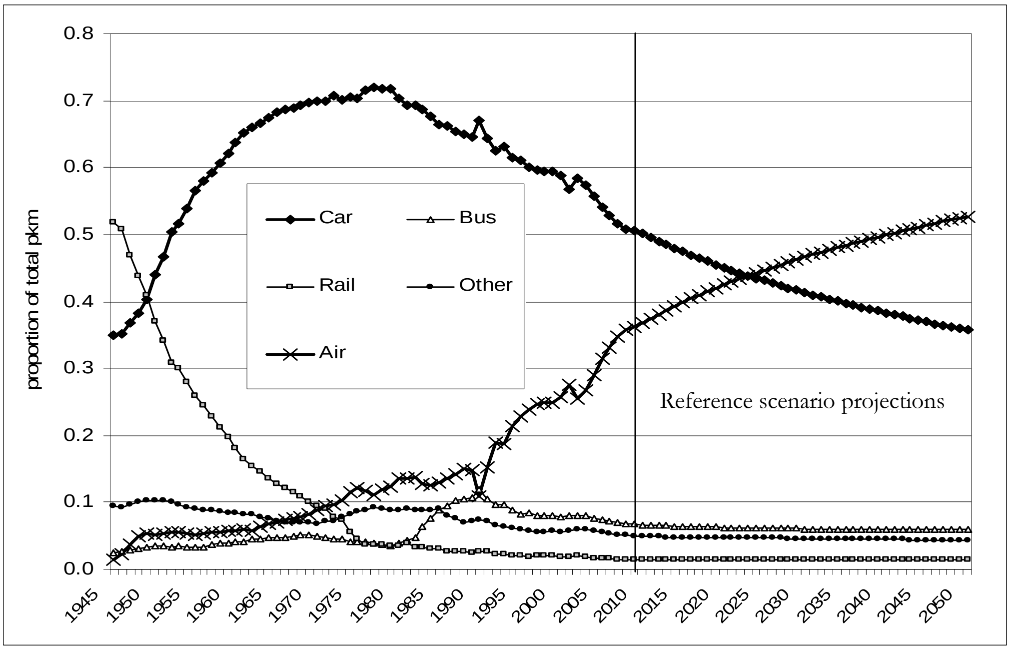


Notes: 'Other road' primarily consists of non-business use of light commercial road vehicles (LCVs), with minor contributions from motorcycles and heavy vehicles.
'Bus' refers to total commercial bus usage in urban areas, i.e. includes passenger tasks not only carried by transit fleets, both privately-owned and government run, but also by any other buses (motor vehicles with 10 or more seats) – including a lesser component of the total task due to charter and hire vehicles.

Sources: BITRE (2008), BTCE (1996), BTRE (2002, 2003, 2006, 2007), Cosgrove (2008) and BITRE estimates.

For non-urban passenger transport, the long-term modal share patterns have certain similarities to the urban case. That is, the major transport mode directly following World War II was once again rail (accounting for over half of total non-urban passenger kilometres), and once again rail lost most of its mode share to road vehicles over the next few decades (see Figure 9). However, the non-urban case differs with the fast growing contribution of air travel—such that, by the end of the 1970s, the modal share of non-urban car travel had begun to decline.

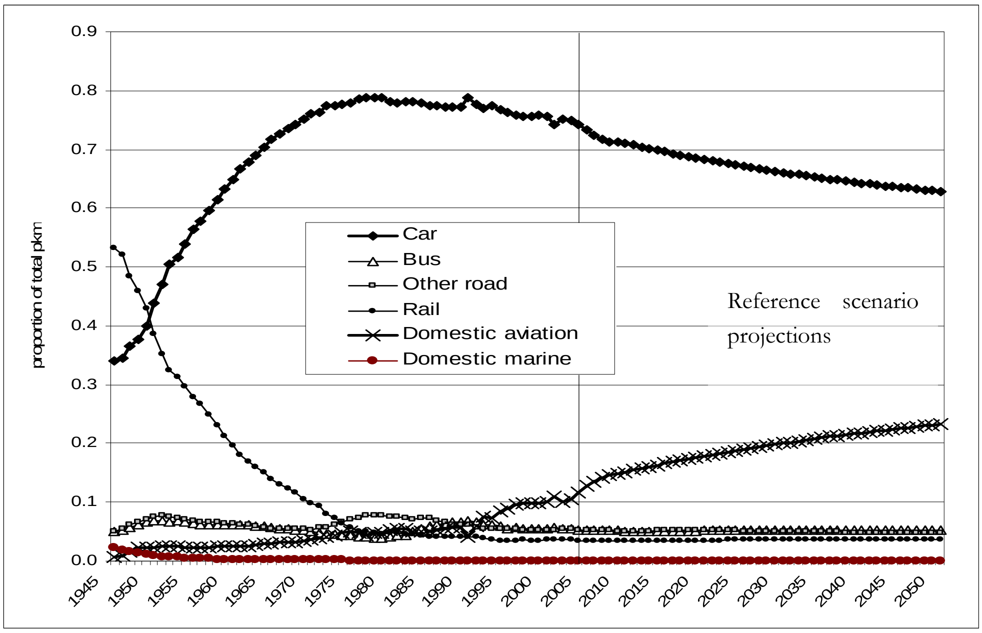
Figure 9 Modal shares for Australian non-urban passenger travel



Note: 'Other' primarily consists of non-business use of light commercial road vehicles, with contributions from motorcycles, heavy vehicles and domestic navigation (interstate ferries and cruise ships).
Sources: BITRE (2008), BTCE (1996), BTRE (2002, 2003, 2006, 2007), Cosgrove (2008) and BITRE estimates.

The combined result of the modelled urban and non-urban modal share trends is displayed in Figure 10 – which gives the mode share projections for the total Australian passenger task, under the reference scenario assumptions.

Figure 10 Modal shares for total Australian passenger travel

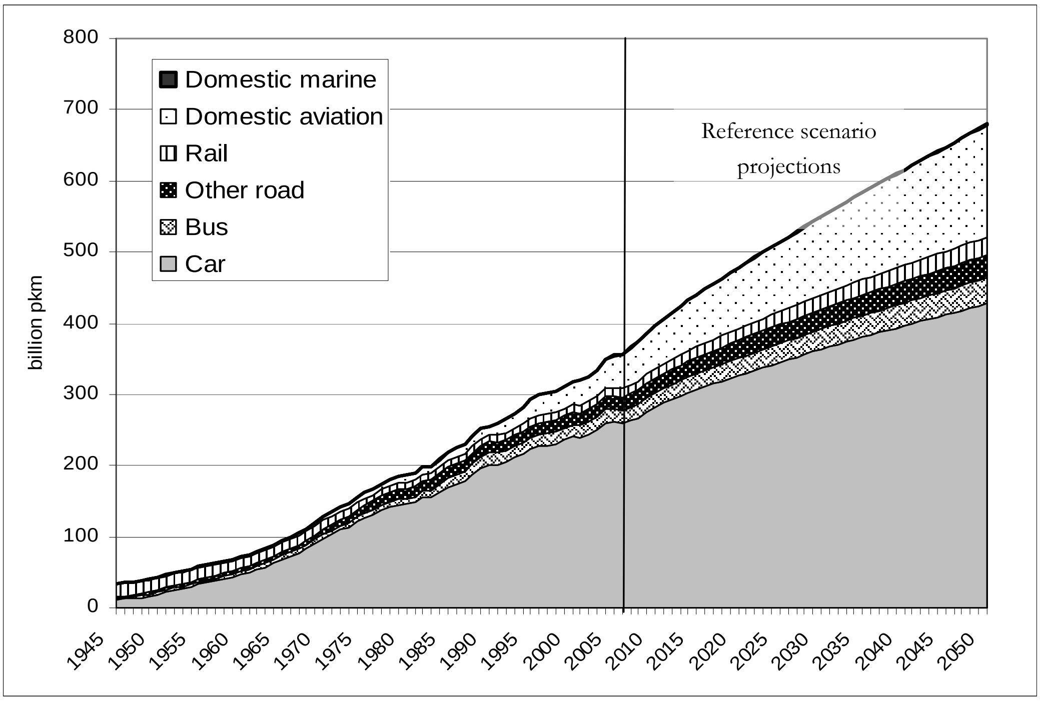


Note: 'Other road' primarily consists of non-business use of light commercial road vehicles.
Sources: BITRE (2008), BTCE (1996), BTRE (2002, 2003, 2006, 2007), Cosgrove (2008) and BITRE estimates.

Aggregate passenger travel projections, 2006–2050

The reference scenario projections of aggregate passenger travel between 2006 and 2050—derived using the total passenger travel demand relationships and mode share models described above—are shown in Figure 11.

Figure 11 Historical and projected passenger movement, Australian total



Note: 'Other road' primarily consists of non-business use of light commercial vehicles (LCVs) - with small contributions from motorcycles and non-business use of trucks.
Sources: BITRE (2008), BTCE (1996), BTRE (2002, 2003, 2006, 2007), Cosgrove (2008) and BITRE estimates.

4 ROAD TRANSPORT ASSUMPTIONS

Assumptions used in the MMRF

Details about general macroeconomic assumptions are discussed in Annex B.

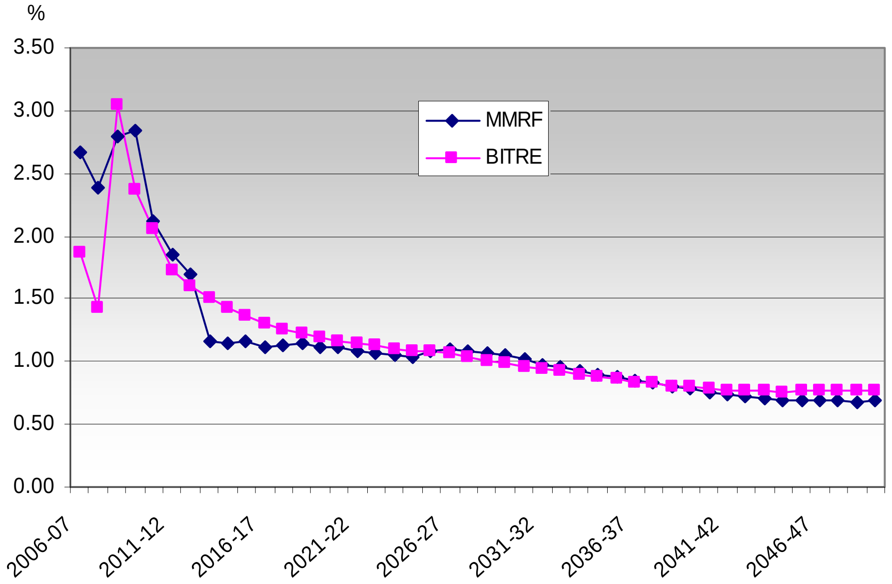
International oil prices

In the reference scenario, it has been assumed that the international oil price would average around AUD$70 from 2020 to 2050. This assumption was based on International Energy Agency projections. See Annex B for details.

Passenger transport

The road passenger transport task in the reference scenario is assumed to closely follow BITRE's forecasts, detailed in the previous section. To incorporate this, the 'taste' parameters in MMRF have been calibrated so that reference scenario road passenger growth is consistent with BITRE's forecasts. In the mitigation scenarios, road passenger transport activity has been made endogenous within MMRF, with these taste parameters held constant from the reference scenario. Figure 12 shows the growth rate of private road passenger transport assumed in MMRF, along with the forecast from BITRE to which it has been calibrated.

Figure 12 Assumed growth in private road passenger transport task 2006-07 to 2049-50, per cent per annum



Road freight transport

Due to the industry-based manner in which freight generation is dealt with by MMRF, BITRE projections of aggregate (long-term) freight demand were not explicitly used in determining freight growth rates for the reference scenario. That is, unlike the case for the passenger task projections (where the relevant MMRF parameters were adjusted to be consistent with BITRE estimates), expected freight growth patterns over the projection period were derived endogenously within MMRF.

However, the resulting MMRF values for the various freight modes are not all that dissimilar from the levels in the current BITRE long-term freight projections—for example, between 2007 and 2040, the average BAU growth for 'Value-added of road freight transport industry' in the MMRF reference scenario essentially matches that of the BITRE (base case) projections of growth in aggregate road freight tonne kilometres. The MMRF road freight results do exhibit faster expected average growth over the last decade of the projection period (basically due to BITRE projections incorporating a gradual decoupling of aggregate GDP growth and freight transport demand over the longer term), with the consequence that BAU growth in road freight averages about 2.51 per cent per annum between 2007 and 2050 within the MMRF projections and about 2.24 within the BITRE projections.

For details on BITRE short- and medium-term freight transport projections see BTRE (2002 and 2006) and BITRE (forthcoming). Cosgrove (2008) describes methods for extending such medium-term projections over the longer term.

Assumptions used in the ESM

Vehicle, fuel and technology assumptions

Fleet average fuel efficiency can be influenced by changes in fuel/vehicle technologies and the shares of vehicle sizes within the fleet. Vehicle size shares have been influenced by a number of factors over the last few decades. Rising oil prices, increasing wealth and changes in workforce participation have lead to some households purchasing a second smaller car. On the other hand, trends in consumer preferences for improved vehicle performance and comfort have tended to mean that some engine-related fuel efficiency gains have not resulted in reduced fuel consumption per kilometre. Currently high oil prices have tended to see an increasing trend toward smaller vehicles and growing interest in vehicles that offer improved fuel efficiency per kilometre.

To reflect these factors, the ESM requires exogenous assumptions about:

- choice of vehicle size (light, medium or large for passenger and light commercial vehicles);
- technology availability and uptake;
- costs of alternative vehicle engine technologies;
- costs of fuels;
- fuel efficiency for each engine, vehicle category and fuel combination.

These are described in the following sections.

Vehicle size assumptions

Average vehicle size was assumed to be remain fixed in ESM for the reference scenario (as a result of an assumed relatively flat trend in MMRF petrol and diesel prices and continuing increases in household incomes). However, vehicle size composition for passenger and light commercial vehicles was assumed to gradually change over time to 2050 in the mitigation scenarios to the amounts shown in Table 2. These assumptions were not based on modelling, but rather relied on views from CSIRO and BITRE. Note that *Garnaut -10* and *CPRS -5* share the same vehicle size assumptions because they arrive at a similar CO_2e permit price of approximately $115 per tonne CO_2e by 2050.

By themselves, the vehicle size share assumptions are in line with an elasticity of fuel consumption with respect to fuel price (holding travel fixed) of around –0.15 for small price changes, which is broadly consistent with the literature.[2]

Table 2: Assumed fleet vehicle size shares under mitigation scenarios

	Vehicle class shares (%) by 2050					
Carbon price	**Light car**	**Medium car**	**Heavy car**	**Light LCV**	**Medium LCV**	**Heavy LCV**
Reference scenario	35	34	31	8	34	59
Garnaut -10 and CPRS -5	45	32	23	16	38	46
CPRS -15	47	31	22	19	39	42
Garnaut -25	50	30	20	20	40	40

Source Assumptions in CSIRO's Energy Sector Model.

Assumptions about technology uptake

The uptake of new fuel and vehicle technology following a carbon price shock was determined endogenously within the ESM on the basis of least cost subject to vehicle fleet turnover limitations and some exogenous constraints such as the vehicle size shares already discussed. In all cases uptake of hybrid electric vehicles is unrestricted. Fully electric vehicles are restricted to 40 per cent of the light vehicle passenger market and 30 per cent of rigid trucks. Uptake of biofuels is limited by availability of appropriate vehicles, and by biofuel supply availability which is discussed further below.

It is assumed that the upfront cost of vehicles is amortised over 7 years, however they may remain in the vehicle fleet for up to 20 years.

Costs of new engine technologies

Figure 13 presents assumed vehicle costs by engine type. Costs are for a representative vehicle in the given weight category (CSIRO, 2008). Over the projection period, vehicle costs are assumed to remain constant for conventional internal combustion engine (ICE) vehicles that do not have any enhanced electrification. For other vehicles, notably for hybrid vehicles, plug-in hybrid electric vehicles (PHEV) and all fully-electric vehicles, costs are assumed to fall. Costs are assumed to fall by a greater amount for the *Garnaut -25* scenario than for the *Garnaut -10* scenario. The *CPRS -5* and *CPRS -15* scenarios are assumed to have the same cost assumptions as the *Garnaut -10* scenario given those scenarios are broadly consistent with that global setting. There are significant uncertainties in terms of the timing and extent of the assumed reductions in vehicle costs. Achieving these cost reductions relies on adequate supply of minerals and other raw materials,

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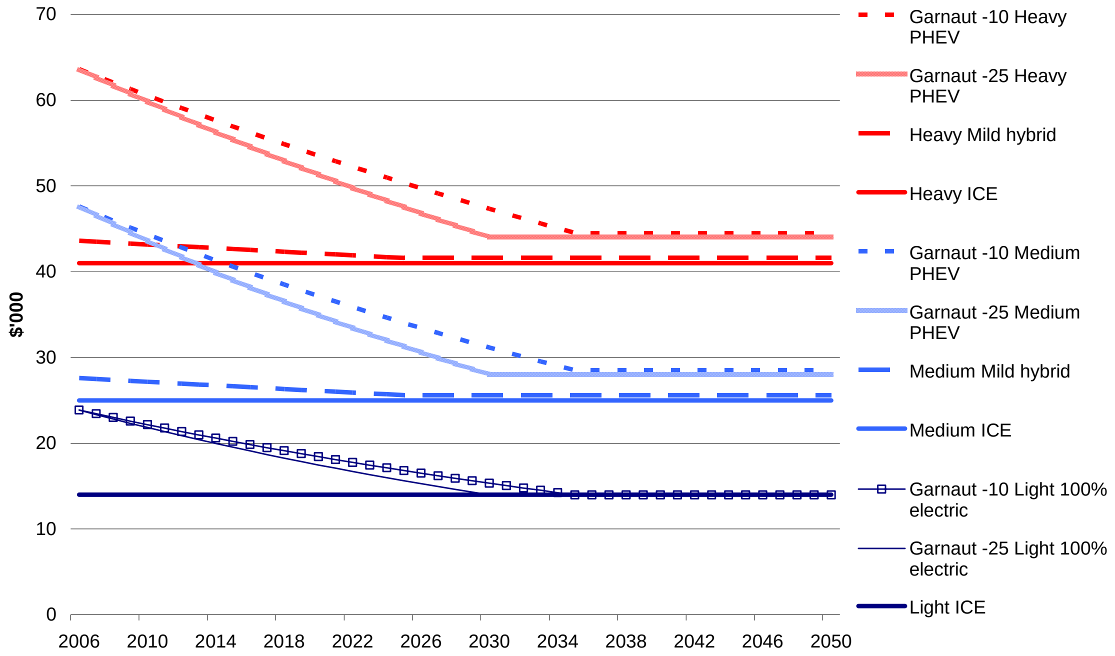
[2] For example, a literature review by Hanly, Dargay and Goodwin (2002) found that the average estimate for the long-run elasticity of fuel consumption with respect to price in post-1981 studies was –0.43, and that the average estimate for the long-run elasticity of vehicle kilometres travelled with respect to fuel price of –0.29 (these two elasticities would imply an elasticity of fuel consumption with respect to fuel price, holding vehicle travel constant, of –0.14).

successful further development of battery and other technologies and realisation of global production economies of scale.

Figure 13 Assumed vehicle costs by engine type and scenario



Source: CSIRO (2008).

Assumed future costs of alternative fuels

Assumptions about future changes in the costs of alternative fuels were based on CSIRO research.

For biodiesel and ethanol, the costs were based on the volume of demand as per the cost–quantity curves in Figures 14 and 15. These curves were derived from O'Connell et al. (2007) and updated further to take account of recent price movements. They show the total amount of biofuels that would be available if all of these feedstocks were converted to biofuels. Full biofuel conversion would not be realistic given the need to produce and export food and the pressure competition between these two industries would put on the price of feedstocks. Therefore it was assumed that only 5 per cent of this volume would be available within the next decade at the prices indicated. The exception to the 5 per cent rule was that all used cooking oil and all tallow not exported was assumed to be available for biodiesel.

From 2020 technology was assumed to be available to use lignocellulose feedstock in ethanol production. This offers the opportunity to use the non-food portion of crop production which offers greater biofuel volumes without significantly affecting the food market. It was assumed this volume enters at the lower end of the cost–quantity curve. As a guide to volumes, around 30 per cent of crop residue could be used, equivalent to 9 000 ML of ethanol (O'Connell et al., 2007). However, feedstocks could also include specialty crops and wood/wood waste. If economically viable this could contribute to around 20 per cent of current fuel requirements.

Similarly, for biodiesel it was assumed algae-based sources are available from 2020 and as a result increase the volume of biodiesel available by a factor of ten. It was assumed this volume enters at the upper end of the cost–quantity curve. Subsequently, algae-based biodiesel does not feature strongly in the modelling outputs. However, it still presents a substantial opportunity if development over the next decade can prove its viability in the lower part of the cost quantity curve. CSIRO (2008) shows that if low cost algae-based biodiesel is available it can contribute significantly to future diesel supplies and transport sector under CO_2e permit pricing incentives.

Figure 14 Bio-diesel cost-quantity curve excluding algae

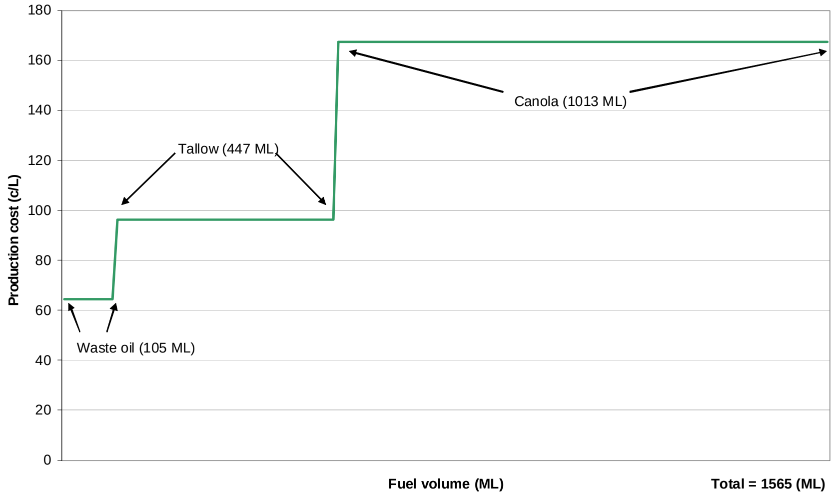


Figure 15 Ethanol cost-quantity curve excluding cellulose

Engine efficiency assumptions

For each vehicle class, future fuel efficiency depends on the extent to which technology improvements are translated into fuel efficiency rather than performance improvements. Reflecting uncertainty surrounding this, literature on future fuel technologies (for example the King Review, King 2007) tends to discuss what improvements would be feasible, and the associated costs, in the near future (around a decade). In most cases some intervention would be required to achieve such rapid changes, and there has been relatively little discussion of what is likely to occur without intervention (for example the King Review "focuses on what can be achieved, through strong action now, towards the long term decarbonisation of cars" (King 2007, p. 4)).

For the reference scenario, it is implicitly assumed all improvements that are technically feasible, but costly to introduce in the near future, will come on line slowly toward 2050, once the costs have been reduced sufficiently to make them competitive.

Table 3 presents assumptions about road vehicle fuel intensity by fuel type for conventional ICE vehicles. These assumptions are consistent with CSIRO (2008) and reflect the most recent thinking about possible scenarios for future fuel efficiency improvement. BITRE has checked them against the literature (as detailed in the notes to the table) and has confirmed that they are within the range of plausible estimates.

Fuel intensities for ICE's were assumed to decline up to 37 per cent between 2006 and 2050. Hybrid electric vehicle fuel intensities were developed based on their performance relative to ICE only vehicles.

It is assumed that the mild hybrid category has a 5 per cent improvement in fuel efficiency starting in 2006 increasing to 30 per cent by 2050 for all non-articulated truck road categories. Articulated trucks improve to only 10 per cent better than conventional articulated trucks.[3] Mild hybrids draw no electricity from the grid.

The assumptions for PHEVs, which do draw electricity from the grid, are more complicated. Total fuel efficiency is calculated on the basis of the percentage of time in which it uses the electric drive train. When using the ICE drivetrain it has the ICE-only efficiency for that year. When using the electric drivetrain it has the following efficiencies:

- Light passenger: not applicable
- Medium passenger: 0.22kWh/km
- Heavy passenger: 0.31kWh/km
- Rigid truck: 0.85 kWh/km
- Bus: 0.8kWh/km

These electric drivetrain efficiencies are held constant over time on the basis that any improvements are used up to provide better amenity (passenger and luggage room, safety, comfort, performance and instruments) rather than fuel savings.

The percentage of time using electric drivetrain in total annual kilometres is assumed to be 50 per cent initially in 2006, increasing to 80 per cent by 2035 as battery technology improves and allows for longer use of the electric drivetrain. For the remainder of total

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[3] Further BITRE checking of CSIRO's assumptions found the following information:

According to Friedrich (2008) "it is possible … to achieve average fuel consumption below 2L/100km". However, King (2007) suggests that hybrid technology in 2050 could be 50% more efficient than conventional in 2007 (according to ITF 2008). Also Chea et al (2007) suggest that currently a medium sized "full hybrid" has fuel consumption of 70% of a medium sized conventional vehicle, and falling by up to 50% by 2035 (depending on what proportion of technical improvement is targeted to fuel economy rather than performance). Jones (2008) reports that current parallel hybrids have fuel consumption 17 to 30% lower than conventional vehicles, depending on vehicle class - lower than the 38% reduction for all classes assumed here.

Langer (2004) suggests fuel consumption reductions through hybridisation of rigid trucks of between 41% and 52%, relative to 2004 conventional engines. Vyas (2003) predicts that hybridisation will reduce fuel consumption (relative to 2003 conventional engine) by 29%.

According to dieselforum.org, hybrid diesel buses used by New York City Transit since 2002 consumed 37% less fuel than equivalent conventional diesel buses.

kilometres travelled the ICE drivetrain is in use. As such, a weighted average of the efficiency of these drivetrain gives the average annual efficiency for any given year.

In all cases, for fuel intensities in intervening years, constant compound growth rates were derived from the two end points. The implied annual growth in fuel efficiency to 2050 for each class is slightly slower than that over the last 30 years (consistent with an apparent slowdown in this growth since the 1980s).

Fully electric vehicles is the final category and it is only applicable for light vehicles and rigid trucks using the electric drivetrain 100 per cent of the time at 0.2 kWh/km and 0.85 kWh/km respectively. Again, these efficiencies are held constant over time on the basis that any improvements in electric drivetrain efficiency are used up to provide better amenity.

Note, at a residential electricity price of 12c/kWh, the cost of electricity as a fuel for light vehicles is 4.2c/km. This is slightly more than a third of the cost of fuel for a petrol vehicle in the same weight class of 11.5c/km at a petrol price of 128c/L. (Retail petrol prices include fuel excise of 38.143 cents per litre and 10 per cent GST.)

Table 3: Assumed fleet average fuel intensity by engine type (l/100km) - conventional vehicles

	Petrol		**Diesel**		**LPG**		**CNG (m^3/100km)**		**B100**		**B20**		**E85**		**E10**		**H2 (m^3/100km)**		**Gas to liquid**		**Coal to liquid**	
	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050
Passenger Cars																						
Light	9.1	6.8	6.3	5.4	12.1	8.6	8.0	5.5	7.7	6.3	6.5	5.6	12.8	8.6	9.5	7.1	36.7	23.3	6.6	5.7	6.6	5.7
Medium	10.2	7.6	7.1	6.1	13.6	9.6	9.0	6.2	8.6	7.1	7.3	6.3	14.3	9.6	10.6	7.9	41.1	26.1	7.4	6.4	7.4	6.4
Heavy	14.0	10.4	9.7	8.3	18.6	13.2	12.3	8.5	11.8	9.7	10.0	8.6	19.6	13.2	14.5	10.8	56.3	35.7	10.1	8.7	10.1	8.7
LCVs																						
Light	10.4	7.8	7.2	6.2	13.8	9.8	9.2	6.3	8.8	7.2	7.4	6.4	14.6	9.8	10.8	8.0	41.8	26.6	7.5	6.5	7.5	6.5
Medium	11.6	8.7	8.1	7.0	15.5	11.0	10.3	7.0	9.8	8.1	8.3	7.2	16.4	11.0	12.1	9.0	46.9	29.7	8.4	7.2	8.4	7.2
Heavy	15.9	11.9	11.1	9.5	21.2	15.0	14.0	9.6	13.5	11	11.4	9.8	22.4	15.0	16.5	12.3	64.2	40.7	11.5	9.9	11.5	9.9
Trucks & Buses																						
Rigid	39.2	29.3	28.9	24.9	52.2	37.0	34.5	23.7	35.2	28.8	29.8	25.6	55.1	37.0	40.6	30.3	157.8	100.1	30.1	25.9	30.1	25.9
Artics	73.1	54.6	54.0	46.4	85.2	69.7	83.4	68.3	65.7	53.8	55.6	47.8	89.9	69.6	75.8	56.6	257.6	199.4	56.2	48.4	56.2	48.4
Buses	36.2	27.0	26.7	23.0	48.1	34.1	31.9	21.9	32.5	26.6	27.5	23.6	50.8	34.1	37.5	28.0	145.6	92.4	27.8	23.9	27.8	23.9

1. King (2007, p. 45) suggests efficiency improvements of 30% are possible within a decade (with policy incentives - not market driven). Cheah et al. (2007) suggest fuel consumption of conventional vehicles could fall up to 40% by 2035 (depending what proportion of technology improvement is targeted to fuel economy rather than performance). Jones (2008) lists improvements that, multiplying together expected benefits, lead to similar reductions in fuel consumption. DeCicco et al. (2001) suggest potential reductions in fuel consumption by 2015 of between 27% and 41% are achievable, for cost increases of between 4% and 7%.
2. Cheah et al (2007) suggest fuel consumption of diesel vehicles is now only 16% lower than petrol vehicles, and could fall at the same rate as for petrol vehicles by 2035.
3. Vyas (2003) suggests most predicted reductions in fuel consumption will come with significant cost increases.
4. Langer (2004) suggests articulated trucks could achieve up to 37% reduction in fuel consumption, by 2015. Vyas (2003) predicts that fuel consumption will fall 39% as technologies are adopted (presumably over the next few decades).

Source: CSIRO (2008).

5 SIMULATION RESULTS

This section reports the simulation results - including the greenhouse gas emissions, fuel consumption, and transport technology uptake - for the reference and mitigation scenarios. Transport demand or activity levels for each scenario are drawn from MMRF results. All other results are sourced from the ESM modelling (which was provided as input to MMRF during the iteration process).

Reference scenario

Road transport activity levels

In the reference scenario, the road passenger task is forecast to grow at an average of 1.1 per cent per annum between 2006 and 2050 (approximately the same growth rate as population). The road freight task is forecast to grow at an average rate of 2.5 per cent per annum (approximately the same growth rate as GDP).

Road transport fuel demand and mix

'Mild' hybrid vehicles (i.e. those without a plug-in capability) become the predominant vehicle technology in the Australian vehicle fleet by 2050, while PHEV and fully-electric vehicles are projected to play only a limited role. Large scale uptake of mild hybrids commences from around 2020. This finding does not ignore the fact that hybrids have already been taken up in the fleet in small numbers. Rather the modelling projects the point at which the majority of new vehicles will be mild hybrids. Largely because of the increase in mild-hybrid use, transport becomes more fuel efficient at a slightly faster rate to 2050 than it has historically. Energy use per vehicle kilometre travelled falls at an average annual rate of 1 per cent for passenger cars, 1.3 per cent for light commercial vehicles, 1.4 per cent for rigid trucks and 0.5 per cent for articulated trucks.

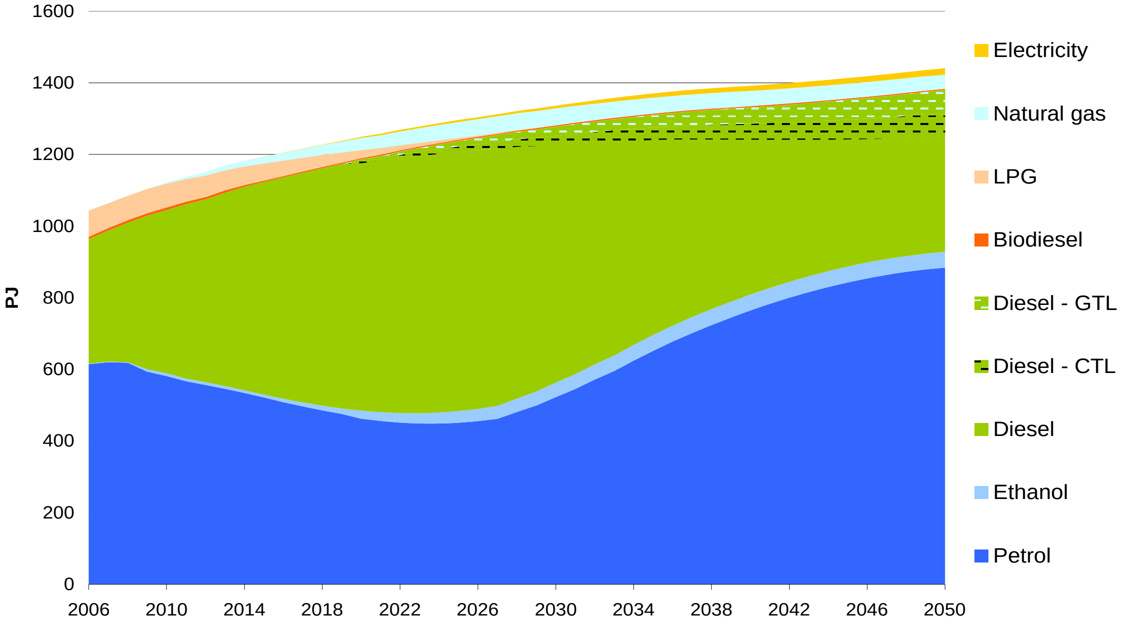
Diesel becomes more significant as a car fuel in the next two decades. The initial increase in the take up of diesel vehicles reflects changing economics of diesel vehicles. The additional cost of a diesel vehicle has to some extent been offset by improvements in fuel efficiency together with the rise in oil product prices since 2004. The increase in diesel engine efficiency is attributed primarily to the availability of European-designed diesel engines, which until recently were not compatible with our diesel fuel as set by the national standards.

From around 2020, petrol consumption recovers as mild hybrids become a cheaper and comparatively efficient vehicle relative to diesel ICE-only. Gas-to-liquid and coal-to-liquid diesel fuels become cost-effective and hold a significant share of the market by 2050. Ethanol, initially in the form of E10 and then E85 once greater volumes of non-food based ethanol are available from 2020, expands its contribution. CNG (mostly in the form of LNG-fuelled trucks) and electricity both emerge as significant fuels from a near zero share at present. The total use of electricity in transport by 2050 is 17 petajoules (PJ) which is equivalent to 5 terawatt hours (TWh). This is around 1 per cent of total electricity production in 2050. LPG use becomes negligible by around 2030, as the current LPG fleet is retired and mild hybrid petrol vehicles become the preferred fuel and engine combination for reducing travel costs.

Figure 16 shows the use of each fuel, in petajoules, from 2006 to 2050 in the reference scenario. Not visible in the chart are hydrogen and biodiesel, neither of which become significant fuels at any time before 2050. Biodiesel, as discussed earlier, is limited by the assumption that traditional feedstocks are limited and algae-based biodiesel will be high cost. If algae-based biodiesel is in fact low cost then it may achieve a large market share. At present its future costs remain very uncertain. Hydrogen was only directly considered as an ICE fuel. Electric vehicles are assumed to be driven by batteries. They could equally have been assumed to be driven by hydrogen fuel cells. Consequently, where ESM projects electric vehicle uptake, this could indicate a future demand for hydrogen if fuel cells are successful in competing with batteries.

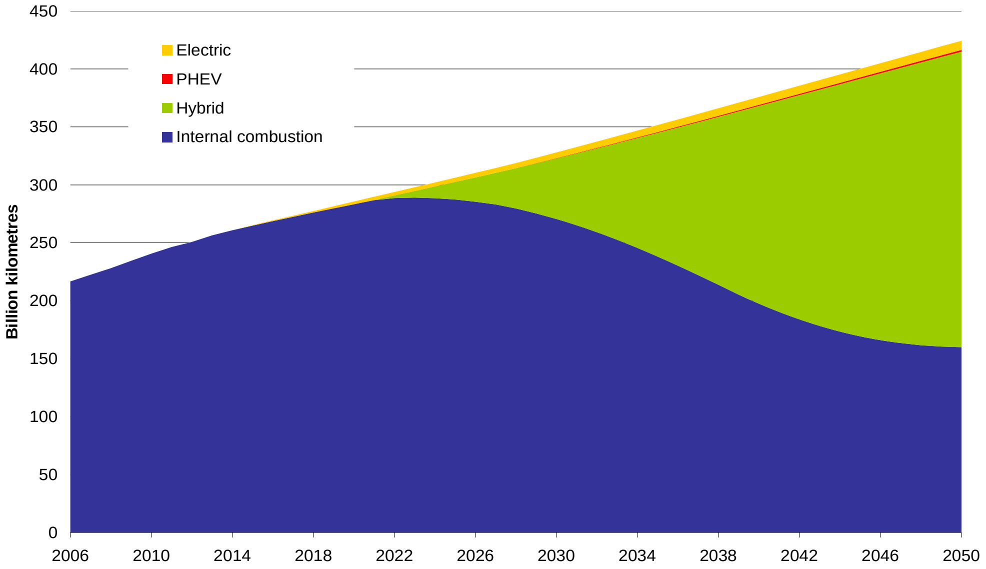
Figure 17 shows engine use, in vehicle kilometres travelled, from 2006 to 2050 in the reference scenario.

Figure 16 Road fuel use in petajoules for the reference scenario



Note: Electricity energy is the final electricity drawn from the grid. This presents a slightly misleading indication of the total primary energy required in the transport sector since all energy losses in the electricity sector are not shown here. That is, while the energy losses from liquid fuels mostly occur in-vehicle and are therefore included in the total transport fuel required (in petajoules), most energy losses in the use of electricity are in the generation stage and are not included in the figure above.

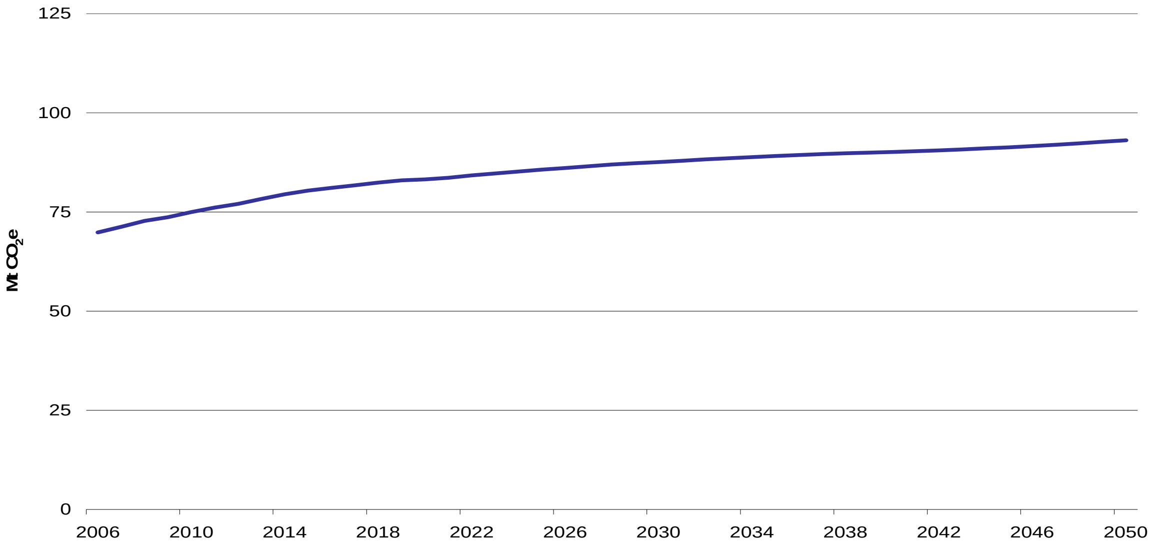
Figure 17 Road engine use, in kilometres travelled, reference scenario



Road transport emissions

As transport energy continues to be sourced from carbon-intensive fuels, emissions per unit of energy do not fall significantly over time in the reference scenario. Overall, emissions per unit of energy fall at an average annual rate of 0.1 per cent from 2006 to 2050. Emissions from road transport (excluding those from electricity used in transport) grow at an average annual rate of 1.3 per cent from 2006 to 2020, and an average annual rate of 0.7 per cent from 2006 to 2050 (as shown in Figure 18). The slowing in emissions growth is driven by the reduction in energy use per vehicle kilometre with greater uptake of hybrid electric vehicles, and by the slowing of population growth. Note that the 5TWh of electricity use by the road transport sector if added to road sector emissions would add around 5MtCO_2e by 2050.

Figure 18 Reference scenario direct road transport emissions 2006-50



Note Emissions from electricity used in transport are not included in this chart

The mitigation scenarios

In the mitigation scenarios, there are three compounding effects that lead to significantly lower emissions relative to the reference scenario:

- Lower road transport activity: In the case of private road passenger transport, the same population demands less private transport. In the case of road freight, GDP is slightly lower than in the reference scenario, and freight transport per unit of GDP is also lower.
- Less energy use per unit of transport: in the case of passenger transport, consumers are able to, and do, choose smaller/more efficient vehicles under the mitigation scenarios.
- Less emissions per unit of energy: for both passenger and freight road transport, there is substitution to lower emission fuels (including electricity).

In each scenario, the proportional reduction in transport emissions is smaller than the reduction in economy-wide emissions, because of the relatively higher abatement costs in transport.

Impact on transport fuel prices

The impact of carbon pricing on transport fuel prices varies between scenarios and over time (Table 4). Overall, the impact of the *Garnaut -25* mitigation scenario on fuel prices is larger than that of the *Garnaut -10* and *CPRS -5* and *CPRS -15* scenarios. For each mitigation scenario, the short-term effects are smaller because permit prices build from a low base and there are fewer abatement technologies available, and at higher cost than later in the projection period. In the CPRS -5 scenario, the road transport sector is exempted from emission pricing for three years, reflecting the Government's Green Paper commitment to provide a transitional period to allow motorists time to adjust to the scheme. The percentage sensitivity of retail prices of transport fuels also depends on emission intensity and cost of fuels, and the level of existing fuel excises.

Table 4 summarises the impact of carbon pricing for each major type of transport fuel, relative to the reference scenario. It shows that changes in petrol prices can be expected to be modest at between 6 and 11 cents per litre at the commencement of the road sector being exposed to permit prices (assumed to be 2013 in this modelling). These changes are significantly less than the total change in petrol prices that occurred as a result of international oil market movements between 2004 and 2008 which were up to 50 cents per litre. A movement of that order of magnitude is projected to result from the *Garnaut -25* scenario but gradually over a period of 37 rather than 4 years (assuming all of the CO$_2$e permit price is passed through to consumers). Under the *Garnaut -10* mitigation scenario, the impact of carbon pricing on petrol prices increases from 6 cents per litre in 2006 to 29 cents per litre in 2050.

Table 4: Indicative impact of carbon pricing on petrol prices

		Emission permit price	Addition to petrol price
		$/tCO2e	c/l
2013	Garnaut -10	24	6.0
	Garnaut -25	43	10.8
	CPRS -5	25	6.2
	CPRS -15	34	8.5
2050	Garnaut -10	115	28.7
	Garnaut -25	199	49.9
	CPRS -5	117	29.2
	CPRS -15	158	39.5

Source MMRF and BITRE estimates assuming permit price fully passed through to petrol price.

Impact on transport activity levels

Table 5 summarises changes to transport activity levels under the *CPRS -5* and the *Garnaut -25* scenarios, relative to the reference scenario. Under the main policy scenario, private road transport grows by less than in the reference scenario, and is around 4 per cent lower by 2050 (equivalent to a slowdown in annual car travel growth between 2006 and 2050 from 1.1 per cent to 1.04 per cent). This is driven by the increasing cost of fuels, and is consistent with more people sharing vehicle trips, making fewer trips and/or travelling shorter distances. There is also some substitution to public transport: passenger rail transport is forecast to grow faster than in the reference scenario, at an average annual rate of 3.1 per cent. Freight activity will also grow slower under this scenario, by around 2.3 per cent per annum. Freight growth slows both because economic growth as a whole slows, and because, on average, freight intensive activities contract more than other activities under an emissions price.

Table 5: Difference in transport activity level relative to reference scenario, %

	CPRS -5					Garnaut -25				
	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Private road	+1	0	-1	-2	-4	0	-4	-4	-5	-7
Hire & reward road	0	0	-2	-7	-10	0	-1	-2	-6	-10

Road transport fuels

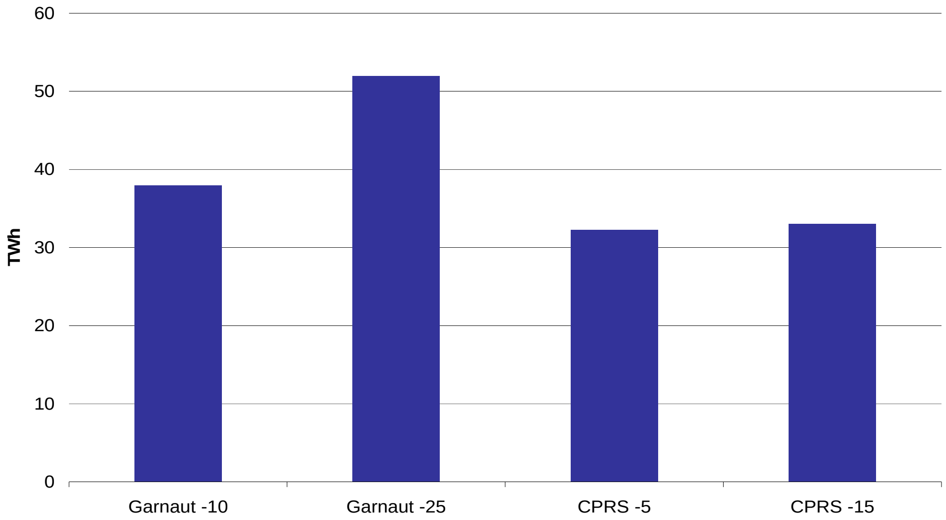
Figures 20, 21 and 22 show the impact on the fuel shares for the *CPRS -5, CPRs -15* and *Garnaut -25*, scenarios. The composition of transport fuels in *CPRS -5* and *CPRS -15* are almost identical because the differences in CO_2e permit prices in these two scenarios are not large enough to cause significant further fuel switching. *Garnaut -10* fuel shares, not shown, are very similar to *CPRS -5*. In all of the scenarios many trends from the reference scenario remain. There is an expansion of diesel in the next decade followed by greater use of natural gas and ethanol from around 2020. LPG use declines with the uptake of hybrid electric vehicles. All of these trends are largely oil price driven phenomena and are a feature of all of the scenarios since the oil price does not change significantly with the introduction of emission trading.

The major impact of emissions trading is to dramatically expand the use of electricity in transport. This is because as electricity generation decarbonises it has an increasing cost advantage as a transport fuel, provided the price of electricity does not increase too dramatically. Each petajoule of electricity used in transport substitutes for many more petajoules of liquid transport fuels since the electric drivetrain is more energy efficient. However, the losses upstream in electricity generation are not shown in these figures and depend on the source of the electricity.

The *Garnaut -25* scenario has the greatest uptake of electricity because the price of CO_2e permits in that scenario reach almost $200 per tonne by 2050 compared to around $115 per tonne in *Garnaut -10* and *CPRS -5* (Figure 19). Higher CO_2e permit prices in *CPRS -15* lead to only slightly higher electricity use because of higher electricity prices.

Other differences in fuel share in response to emissions trading are that use of E10 contracts substantially in favour of an E85 blend (aggregated into total ethanol consumption in Figures 20-22). This is because E10 does not provide substantial emission benefit over petrol. However, ethanol blended as E85 offers significant emission reduction relative to petrol and therefore lower transport costs as the CO_2e permit price increases. However, the E85 vehicle fleet does not initially exist, hence there is a delay where E10 initially expands.

Figure 19 Electricity consumption in road transport by 2050



Another change is that most biodiesel is used as a near 100 per cent blend. Similar to ethanol, a higher blend offers the most cost effective use of the limited biodiesel resource as CO_2e permit prices rise.

The final major difference to the reference scenario is that the synthetic fuels, gas- and coal-to-liquids diesel, do not feature in the fuel mix. This is because the CO_2e permit price has eroded their competitiveness with both processes requiring greater emissions per delivered quantity of diesel fuel (on an energy equivalent basis). Note that CSIRO (2008) shows that synthetic gas and coal diesel production could be viable under emissions trading if oil prices are higher relative to gas and coal prices.

Figure 20 Road fuel use in petajoules in the *CPRS -5* scenario

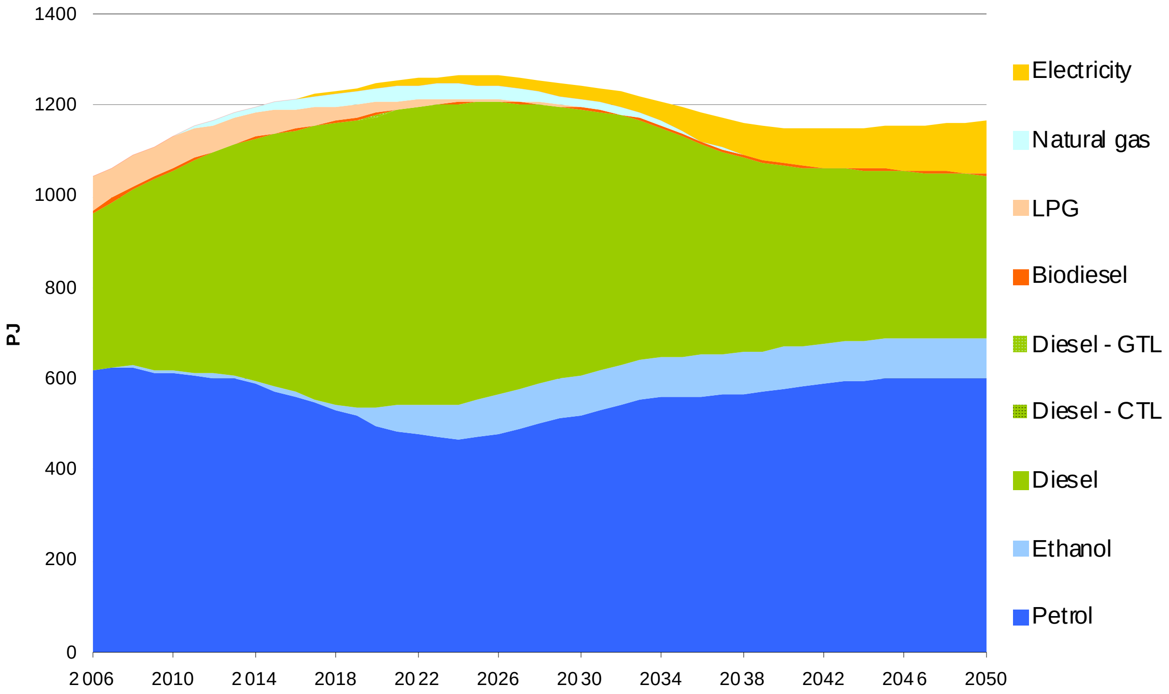


Figure 21 Road fuel use in petajoules in *CPRS -15* scenario

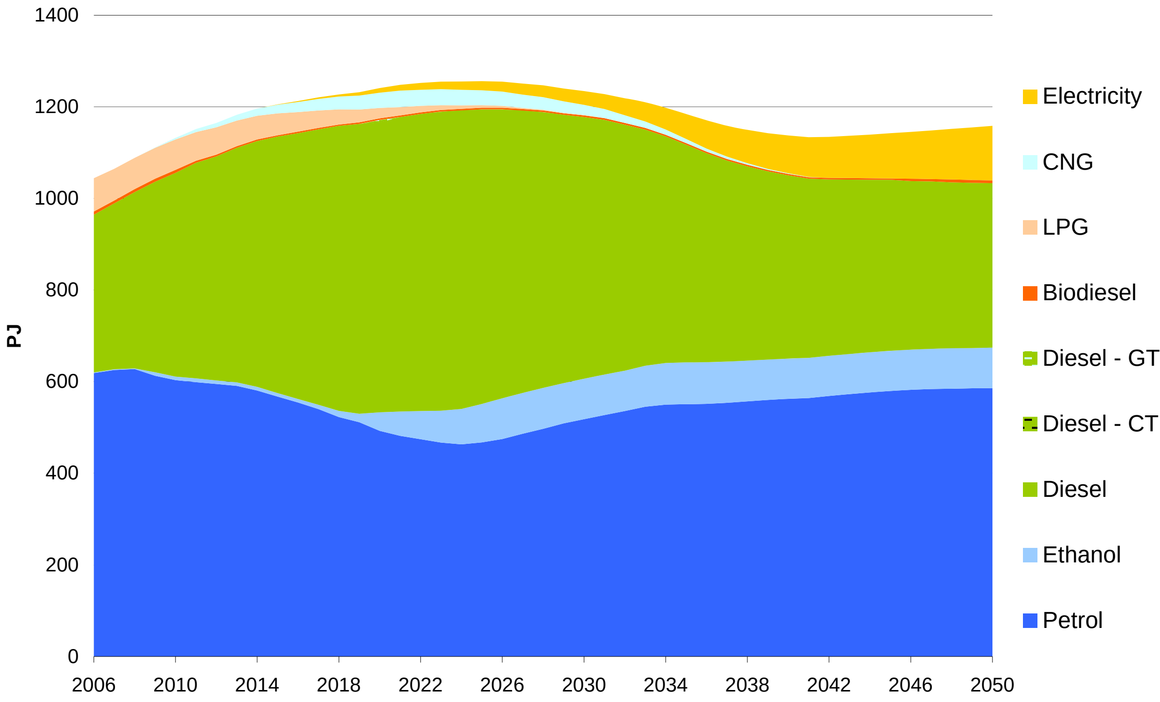
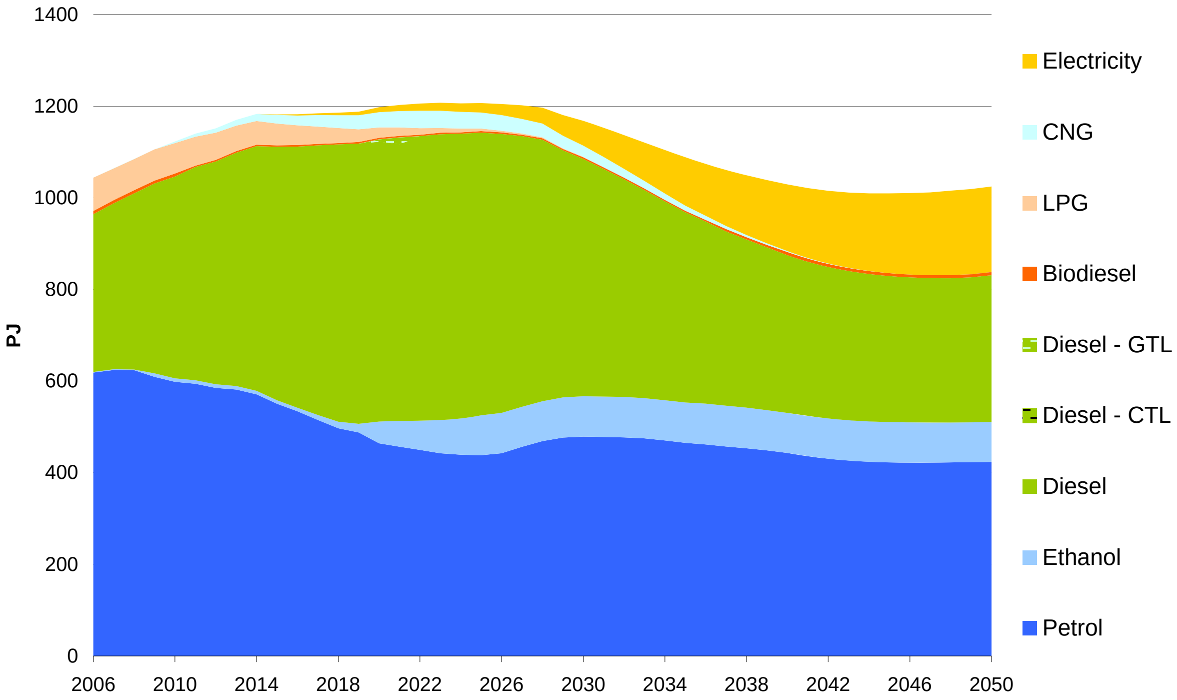


Figure 22 Road fuel use in petajoules in *Garnaut -25* scenario



Figures 23 and 24 show the uptake of alternative engine types as a share of road kilometres travelled. It shows that as the CO_2e permit price rises consumers prefer greater electrification via fully electric and PHEVs in order to reduce road transport costs. Consequently the share of mild hybrids and ICEs declines relative to the reference scenario.

The projected share of kilometres fuelled by electricity by 2050 in *Garnaut -25* is 41.1 per cent. This compares well with the 40 per cent share that was projected by the International Energy Agency (2008) for a scenario with a similar global greenhouse gas abatement task and CO_2e permit price. The projected share for *CPRS -5* is 21.5 per cent.

Figure 23 Vehicle use by engine type in *CPRS -5* scenario

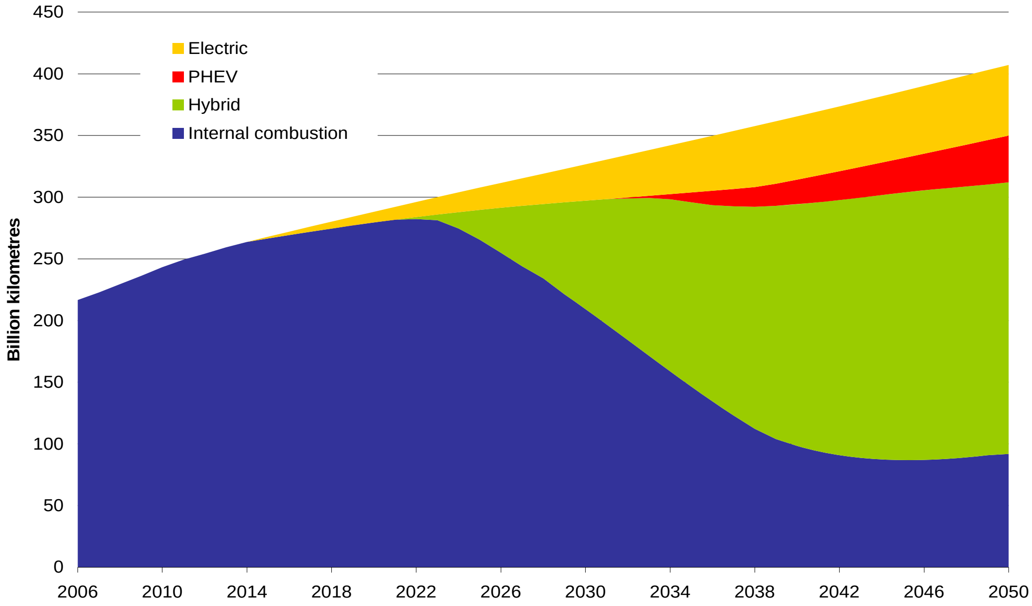


Figure 24 Vehicle use by engine type in *Garnaut -25* scenario

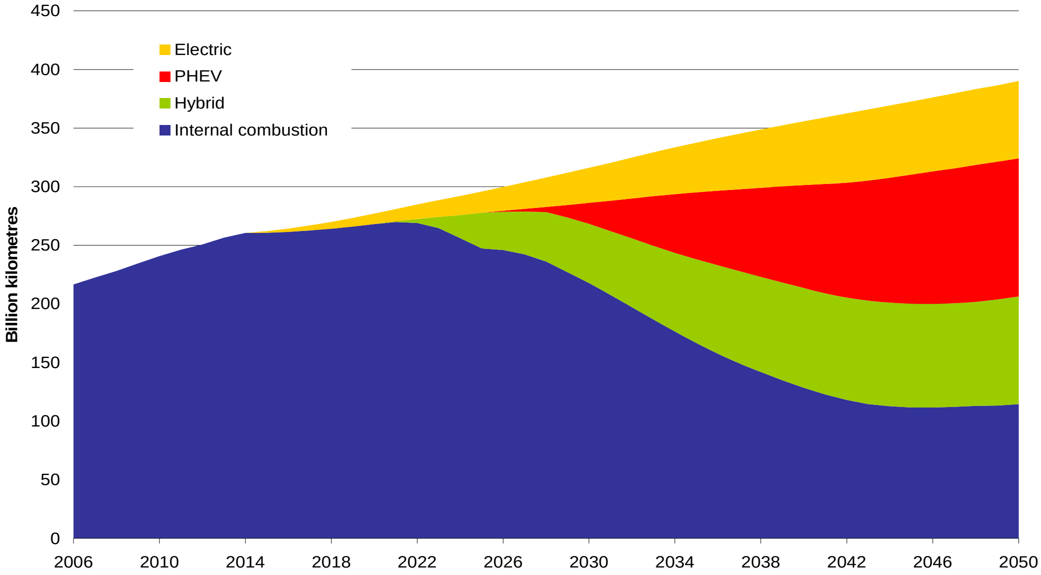


Table 6 shows the changes in fuel and emission intensities by vehicle type under the mitigation scenarios as well as under the reference scenario. They show that, compared to the reference scenario, in the mitigation scenarios the emission intensity of travel declines around twice as fast, the emission intensity of fuels declines around 9 times as fast and the fuel intensity of travel declines around one and half times as fast. These rates of change represent a significant break from past trends and are only achievable mainly due to electrification, which leads to a rapid increase in fuel efficiency within the transport sector by transferring a significant amount of energy conversion losses to the electricity sector. Electrification also leads to a rapid reduction in emissions per kilometre since the emissions intensity of electricity reduces by around 80 per cent—an amount not achievable with any other transport fuel except some forms of biodiesel.

Table 6: Changes in fuel and emission intensities by scenario

per cent per annum, 2006-2050

	Emission intensity of travel (kg CO_2/km)	Emission intensity of fuels[a] (kg CO_2-e/MJ)	Fuel intensity of travel[b](MJ/km)
All vehicles			
Base case	-0.87	-0.08	-0.79
Garnaut -10	-1.57	-0.43	-1.14
Garnaut -25	-2.04	-0.68	-1.37
CPRS -15	-1.38	-0.28	-1.10
Cars			
Base case	-1.02	-0.03	-0.99
Garnaut -10	-1.77	-0.32	-1.45
Garnaut -25	-2.28	-0.74	-1.55
CPRS -15	-1.66	-0.21	-1.45
Trucks			
Base case	-0.96	-0.10	-0.86
Garnaut -10	-1.46	-0.35	-1.11
Garnaut -25	-1.57	-0.43	-1.14
CPRS -15	-1.11	-0.16	-0.95

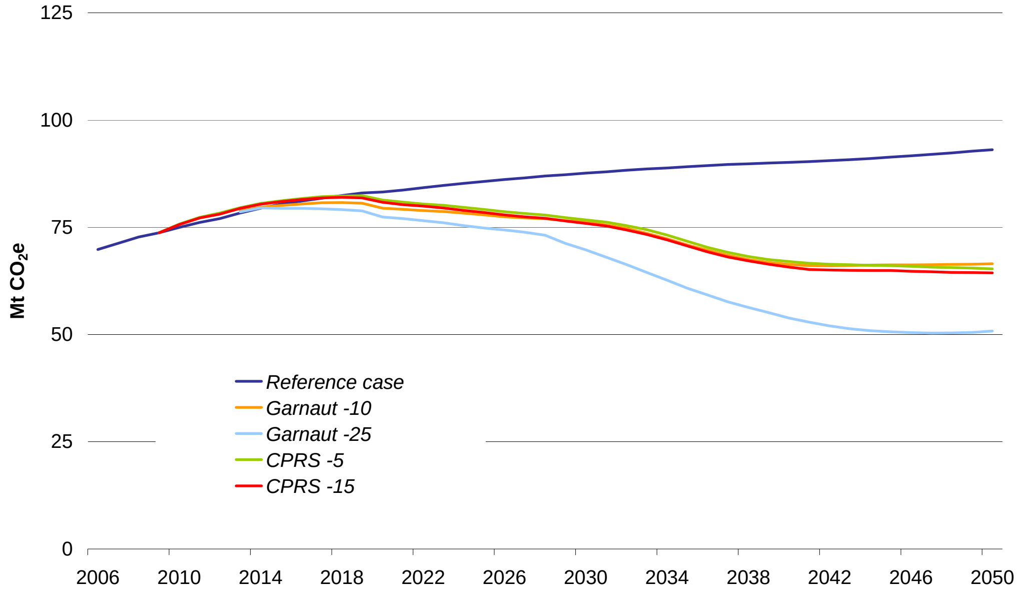
a. Emissions from the electricity used for transport purposes were assumed to be zero (direct).
b. Energy loss during the electricity generation was not taken into account.
Source: ESM 2008.

Impact on transport emissions

Figure 25 summarises changes in emissions for the road transport sector under each scenario. By 2050 the *CPRS -5*, *CPRS -15* and *Garnaut -10* scenarios which share common assumptions for technological change and similar CO_2e permit prices of around $115 to 157 per tonne CO_2e are projected to experience a 29 to 31 per cent reduction in emissions by 2050 relative to the reference scenario. One might have expected the *CPRS -15* scenario to have a higher level of abatement since it is defined by higher CO_2e permit prices (around $157 per tonne CO_2e) than the *CPRS -5* and *Garnaut -10* scenarios. However, the greater incentive for electrification provided by the CO_2e permit price was offset by higher electricity prices.

In the *Garnaut -25* scenario, which has higher CO_2e permit prices of up to around $199 per tonne CO_2e and a faster rate of technological change, emissions are reduced by 45 per cent by 2050 relative to the reference scenario. While electricity prices are higher in the *Garnaut -25* scenario the increase is not significant enough to offset the additional incentive of higher CO_2e permit prices.

Figure 25 Road transport sector greenhouse gas emissions by scenario



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