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Greenhouse gas abatement potential of the Australian transport sector

Technical report from the Australian Low Carbon Transport Forum

An initiative of the ARRB Group, Bureau of Infrastructure Transport and Regional Economics and CSIRO

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Glossary and abbreviations

Abatement options	Options that lower GHG emissions. Forty-seven abatement options were considered such as fuel and vehicle technologies, urban transport measures, new and alternative infrastructure and options to modify behaviour via regulation and price signals.
Aggregate scenario	Evaluates the maximum abatement by 2050 from the chosen options all acting together.
ALCTF	Australian Low Carbon Transport Forum
Alternative fuels	In the context of this report, 'alternative fuels' are combustible fuels other than conventional petrol, diesel, heavy fuel oil and aviation fuel, which can be used in existing internal combustion engines in vehicles, aeroplanes, and ships. This includes less carbon-intensive forms of conventional fuels, biodiesel, ethanol, natural gas and hydrogen. Use of electric vehicles is also an 'alternative' to conventional fuels.
ATRF	Australasian Transport Research Forum
Avtur	Aviation turbine fuel
Base case scenario	Projections of transport tasks, energy-use and emissions over the longer term (to 2050, base year 2010), estimated using primarily 'business-as-usual' (BAU) assumptions for future years. The particular scenario used is sometimes termed a 'Base case with measures' since it incorporates the impact of the likely progress, over the medium term, of various greenhouse gas abatement measures that Australian governments have already implemented or fully framed. The Base case provides the 'reference' values against which the abatement values are calculated.
BAU	Business as usual. In the context of this report, BAU refers to the emission projections resulting from no further action to reduce transport sector emissions other than existing initiatives/measures and considerations regarding probable future movements in travel behaviour and developments in technology. Also referred to as the 'base case' or 'reference' scenario.
Behaviour change	A shift in the use of transport options by the community. As an example, if 25 per cent of current public transport users shifted to walking for half of their trips, this represents a behaviour change.
BITRE	Bureau of Infrastructure, Transport and Regional Economics
Carbon dioxide equivalent (CO_2e)	A quantity that describes, for a given mixture and amount of different greenhouse gases, the amount of CO_2 that would have the same contribution to global warming when measured over a specified timescale (generally 100 years). Calculated using estimated global warming potentials (GWPs).
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
Direct greenhouse gas emissions	Directly radiative gases (i.e. gases in the atmosphere that absorb and emit radiation within the thermal infrared range, where this process is the fundamental cause of the greenhouse effect) as opposed to indirectly-warming gases such as ozone-precursors like carbon monoxide. The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone. Following NGGI guidelines, the combustion gases

	accounting for CO_2 equivalent values by transport include emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Some texts use 'direct GHG emissions' to refer to emissions from a particular source or reporting entity, and 'indirect GHG emissions' to emissions that are a consequence of the activities of that reporting entity (but occur at sources controlled by another entity). This convention is not used here (this report deals with this issue under 'full fuel cycle' emission reporting).
Domestic aviation	The portion of the transport task undertaken by the civil aviation sector within Australia.
Domestic shipping	The portion of the freight transport task undertaken by the maritime sector for coastal freight within Australia.
FFC	Full fuel cycle values include not only energy use during vehicle operation, but also energy used during fuel processing and supply (including petrol refining, biofuel feedstock cultivation and electricity generation).
Freight efficiency	This broad term describes the efficiency of the freight transport task. As there is no specific measure of freight sector efficiency, the term is used here to describe any means of improving emissions intensity of unit freight tasks (grams of CO_2 equivalent emitted per tonne-kilometre performed), and can cover aspects of vehicle design and traffic management.
GDP	Gross Domestic Product. The total market value of all goods produced and services provided within a country during a given period, typically twelve months.
Gg	Gigagrams (10^9 g or a thousand tonnes)
GHG emissions	Greenhouse gas emissions
GWP	Global warming potentials. The NGGI uses values of 21 (times the effects of the same mass of CO_2) for methane and 310 for nitrous oxide.
Hard infrastructure	Involving physical changes to the built environment or its energy inputs
Indirect greenhouse gas emissions	Indirectly radiative gases (i.e. gases such as the ozone precursors carbon monoxide, hydrocarbons and nitrogen dioxide that do not directly emit heat themselves, but where their presence in the atmosphere contributes to the concentrations of the direct greenhouse gases).
Individual abatement potential	The individual impact of each option 'in isolation' (i.e. the abatement impact that the option would have if all else stayed the same).
IPCC	Intergovernmental Panel on Climate Change
Likely case	The expected outcome based on a subjective assessment of all potential barriers
Maximum abatement potential	The amount of transport emission reductions (relative to currently expected trends) judged, through discussions of the participating organisations, to be approaching the limits of social and economic constraints but remaining technically feasible.
Mode shift	The transferral in use of one transport mode to another. In the context of this report, mode shift primarily refers to existing passenger vehicle users shifting to other modes, such as public transport, cycling, or walking, and the shifting of freight between heavy road vehicles and rail or sea transport.
Mt	Megatonnes (million tonnes)

Passenger vehicle efficiency	The fuel/energy efficiency of the vehicles used in passenger transport.
Pkm	Passenger kilometers
Price signals	Changes in retail prices, taxes or other charges that not only offer their own intrinsic abatement (through behaviour changes), but also act as incentives for further change (i.e. are enablers of other options, such as increased adoption of energy saving technology).
NGGI	The National Greenhouse Gas Inventory. The compilation of Australia's emissions data, undertaken by the Department of Climate Change and Energy Efficiency in Australia.
NO_x	Nitrogen oxides – nitrogen oxide (NO) and nitrogen dioxide (NO_2)
NMVOCs	Non-methane volatile organic compounds (primarily hydrocarbons)
PMB	Polymer Modified Binders
Soft infrastructure	Primarily involving changes to information and communication technology systems or their operation
SO_x	Sulphur oxides – such as sulphur dioxide (SO_2)
Transport infrastructure	The physical networks of paths, roads, rail, and waterways, and associated facilities such as parking and fuelling facilities, air and sea ports, and tram, train and bus stations.
Travel reduction	Reducing the amount of travel undertaken.
Transport management	A general term used to describe techniques and methods of organising, controlling, communicating within and monitoring the transport sector, and can include high-level policies, design and implementation, and technologies. Includes travel demand management (TDM) and traffic management.
UPT	Urban public transport
Urban design/planning	In this report, one of the abatement options considers changes to standard urban design focussing on an appropriate co-location of functions (e.g. amenity, employment and living space) so that individual travel intensity is reduced.
UNFCCC	The United Nations Framework Convention on Climate Change. The convention is responsible for setting an overall framework for intergovernmental efforts to address challenges proposed by climate change.
VKT	Vehicle kilometres travelled
WMA	Warm mix asphalt

Introduction

The Australian Low Carbon Transport Forum (ALCTF) was initiated by a project secretariat comprising ARRB Group, BITRE and CSIRO. It was organised to bring together knowledge on the options for greenhouse gas abatement in transport and explore how deeply emissions could be cut in the sector. A report describing the main findings of the study has been published under the title *Greenhouse gas abatement potential of the Australian transport sector: Summary report*.

This current Technical Report is a companion document to the Summary Report, and aims to detail the methodology and results of the ALCTF process. That is, it describes how the estimated levels of abatement were calculated for each of the abatement options considered in the ALCTF workshops, and how the various abatement potentials were aggregated into an estimate for the maximum potential reduction[1].

The ALCTF consisted of a human process (expert elicitation) and a technical process (abatement calculation). The following sections describe the methodologies for both. The third section outlines the reference case emissions against which the abatement is calculated. Finally the report outlines the calculated level of abatement for the options, combined together in total and individually.

[1] Where 'maximum abatement potential' means the amount of transport emission reductions (relative to currently expected trends) judged, through discussions of the participating organisations, to be approaching the limits of social and economic constraints but remaining technically feasible.

Workshop Methodology

The Australian Low Carbon Transport Forum (ALCTF) was designed as an expert elicitation process, whereby information was sourced from transport industry stakeholders and decision-makers, and collated with existing relevant publications and research. This was undertaken in order to synthesise views and knowledge on carbon challenges in transport via workshops, networking and information exchanges, and formed the basis of the ALCTF.

A diverse range of participants were recruited to contribute their expertise to the Forum, including representatives from national and state government, industry, universities and not-for-profit organisations. A listing of participating organisations is provided earlier in this document.

Commencing July 2011, three workshops were conducted. These included:

- Workshop 1 – Project overview, sharing of collective knowledge base, brainstorming of abatement options and their potential and identifying initial knowledge gaps and strategies for addressing them
- Workshop 2 – Reviewing project secretariat analysis of input from the previous workshop including preliminary estimates of the quantity of abatement provided by each option, sharing additional information, defining the remaining uncertainties and the challenges they represent
- Workshop 3 – Reviewing the draft report of workshop analyses, outcomes and lessons.

The process, which reflects these objectives for Workshop 1, 2 and 3 is set out in Figure 1.

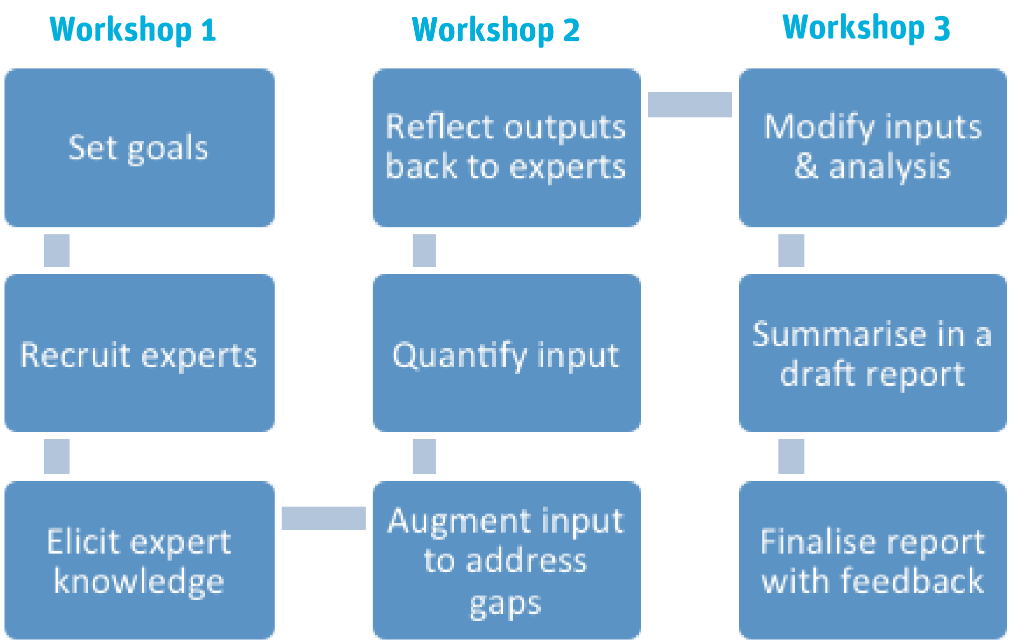


Figure 1: Project process for Workshops 1, 2 and 3.

Overview of Workshop 1

Prior to Workshop 1, the ALCTF project secretariat (ARRB Group, BITRE and CSIRO) worked to set clear goals for the study so that once the experts were recruited and assembled into workshops it was clear what expert knowledge was to be elicited from them.

In Workshop 1, the objectives of the Forum were set out as follows:

- Identify the full range of transport sector abatement options
- Consolidate the abatement options identified and discuss their potential magnitude for greenhouse gas abatement
- Identify what factors limit the potential of each option
- Discuss the potential for increasing the effectiveness of each option.

Standard group and plenary deliberative processes were applied together with a set of instructions and questions to elicit the required information. An overview of the steps is set out in Figure 2.

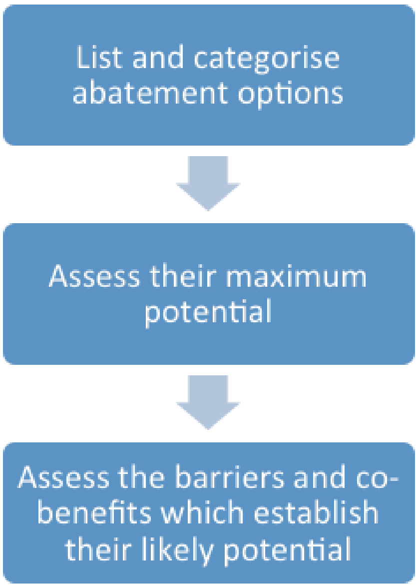


Figure 2: Workshop 1 process.

The following question was posed to the Forum participants:

> 'What are the options available for reducing the greenhouse gas emissions associated with transport in Australia?'

The objective was to seek the views from all participants individually to both ensure the widest possible list and encourage the participation of those who were less inclined to assert themselves in group discussion.

An extensive list of possible abatement options resulted from the initial workshop brainstorming. These were divided into two groups – with the first group (shown in Table 1) containing those options considered to have the most significant aggregate abatement potential. The remaining options, placed in the second group, are shown in Table 2. Though specific features of these supplementary options were not discussed further at the workshop, they include many measures that would complement or enhance the action of the main options selected. The participants spent the rest of Workshop 1 examining the main abatement options in greater detail.

Table 1: Main abatement options for further assessment, Workshop 1

	Category	Initiative/Actions
1	Travel reduction	Urban planning and design / densification / facilities provision
		Telecommuting / video conferencing
		Behavioural change/walking due to information and infrastructure
		Necessity of infrastructure improvements / changing priorities for road provision
2	Alternative fuels	Electric passenger vehicles
		Electric heavy vehicles
		Biofuels
		Natural gas
		LPG
		Hydrogen
		Further diesel use
3	Energy efficiency of passenger transport	Traffic / congestion management
		Engine efficiency
		Lighter vehicles
		Micro-vehicles (e.g. power-assisted bicycles)
		Driving styles
		Accelerate fleet turnover / vehicle checks
4	Energy efficiency of freight transport	Larger trucks (e.g. B-triples)
		Accelerate fleet turnover
		Maximise load through planning / logistics
		Driver behaviour
		Truck engine efficiency
		Consumption choices / ‘food miles’ considerations
5	Mode switching	Road to rail freight
		Road to rail passenger
		Road or rail freight to shipping
		Car passenger to public transport (bus or rail)
		Car to walk/cycle/power-assist
6	Transport infrastructure materials	Pavement design
		Pavement materials
		Construction processes
		Optimising asset utilisation

Table 2: Supplementary abatement options identified by participants, Workshop 1

Category	Initiative/Actions
Urban and regional transport policy	Increasing utilisation of existing transport assets and services
	Increasing public transport network coverage and capacity, and staging supply ahead of demand
	Intensifying land use around transport assets
	Providing accessible public transport for mobility impaired users
	Improving the value proposition for public transport (fares, quality of service)
	Assessing proposed developments in the context of emissions impact
Logistics	Increasing planning for logistics in regional areas
	Providing high-speed rail between major cities/urban centres
	Improving integration of modes, including inter-modal facilities
Tax reform	Possible impacts of carbon pricing on road transport
	Aligning heavy vehicles charges with environmental impacts
	Aligning parking charges with emissions (lower charges for more efficient vehicles)
	Reforming taxation to increase alternative fuel use
Regulation	Improving recyclability and reusability of vehicles
	Including modal accessibility in building energy ratings
	Introducing life-cycle emission rating for vehicles
	Requiring freight operators to monitor and minimise fleet emissions
	Evaluating life cycle energy consumption in infrastructure projects
	Mandating recycled materials in infrastructure projects
Information	Raising awareness of individual carbon footprints in the community
	Introducing emission labelling for second-hand vehicle sales
	Continuing behaviour change programs for travel decisions
	Encouraging use of more sustainable transport options
	Providing life-cycle emissions data for consumer goods (incorporating transport emissions)
	Encouraging alternatives for work-related travel
Government grants	Investing in alternative (low carbon) fuel production
	Providing research funds for second generation emission reduction technologies
	Providing incentives to increase demand for low emission vehicles
	Providing relocation assistance to reduce travel emissions
	Funding information programs aimed at transport behaviour change
	Increasing funds for communications infrastructure and technologies

Participants were then asked to select an abatement option category and attempt to answer the following questions:

- What is the abatement impact of this option if adopted: low, medium or high?
- What is the maximum potential adoption of this abatement option (ignoring social and economic constraints) by 2020 and 2050?
- What is the likely potential adoption by 2020 and 2050 including all constraints? What are the greatest barriers and co-benefits that should be considered, and what policy actions could improve this outcome?
- How do you rate the state of knowledge of this abatement option? (e.g. What are the major knowledge gaps concerning its likely effectiveness and uncertainties about its future implementation?)

These results were collated in the record of the workshop, and were used by the project secretariat as the initial set of abatement options that would be quantitatively estimated and reflected back to the participants in Workshop 2.

Overview of Workshop 2

The aim of the second ALCTF Workshop was to engage with participants to further refine the thinking about the carbon abatement options for Australia's future transport.

The objectives for this refinement discussion were to:

- Utilise the first draft and capture the expert group's knowledge in the context of:
  - reviewing the broad categories and individual options as they were currently scoped
  - refining the assumptions used by the project secretariat to calculate the level of abatement for each option from Workshop 1, and making data corrections
  - identifying critical knowledge gaps impacting on evaluation of the options
  - reviewing the abatement options in terms of co-benefits each may have and caveats that a policy-maker should bear in mind about the options and the overall abatement estimates.
- Clarify the next steps for the project secretariat.

An outline of the methodology used to calculate the options was provided to the Workshop participants, including discussion of the base or 'reference' case emissions (against which the abatement was calculated), the estimated fraction of modal emissions avoided by each option, and thus the emissions abatement potential of the options. Worked examples were also provided to help explain the methodology applied to estimate the various option potentials (such as for radical vehicle fuel intensity reduction, urban road pricing or improved infrastructure materials).

The evaluation framework was provided to estimate the potential savings in emissions for a range of the options suggested by participants of Workshop 1. This involved:

1. Estimation of the degree to which the option might be adopted for 2020 and 2050
2. Specifying the base case (out to 2050) emissions the option applies to
3. Evaluation of the fraction of the base case emissions that might be saved with full adoption
4. Multiplying 1 by 2 by 3 to get the potential emission reduction.

Between Workshop 1 and Workshop 2, significant work was undertaken by the Project Secretariat to collate the available material (from Workshop participants and the literature) and extend the estimates of possible degrees of adoption and technical potential for the various abatement options. The categories identified initially in Workshop 1 (see Tables 1 and 2) were re-classified for the Workshop 2 discussion and assessment (expanding on some areas, to enable as wide a coverage of alternatives as possible, and compressing or aggregating others, typically to aid computational simplicity).

The participants were asked to assess the estimated abatement potentials across the following categories:

- Urban design/planning
- Behaviour change
- Passenger vehicle efficiency
- Price signals
- Mode shift
- Freight efficiency
- Domestic shipping
- Domestic aviation
- Transport management
- Alternative fuels
- Travel reduction
- Transport infrastructure.

Table 3 lists the particular possibilities assessed for Workshop 2. The list includes policy options such as urban road pricing or the control of grossly polluting vehicles. A second major category of options included in the list are technology prospects such as enhanced vehicle fuel efficiency or second-generation biofuels, for which eventual fleet uptake could partially depend on the implementation of other policy measures, as well as the resulting trends in fuel, vehicle and infrastructure prices. The list also includes some behavioural or longer-term lifestyle changes such as resulting from workplaces allowing greater use of telecommuting or greater adoption of walking following urban re-design. Combining behavioural and technological changes, the list also includes possible changes that could be expected from higher (than base case) oil prices[2].

[2] Note that policy options impacting directly on fuel prices are not assessed here – since any climate-change related alterations to energy prices will be handled though the national carbon pricing scheme included within the Government's Clean Energy Legislative Package. Future options considered in the ALCTF process relate to measures that are complementary to the operation of the national carbon price. For some indications of the expected response of the Australian transport sector to higher fuel prices, see Chapter 4 of BITRE (2010) BITRE (2012), recent Treasury modelling (Commonwealth of Australia 2011a, 2011b), Graham & Reedman (2011), and Reedman & Graham (2011).

Table 3: List of individual abatement options by category, analysed for Workshop 2

Category	Option
Behaviour change	Eco-driving
Passenger vehicle efficiency	Radical fuel intensity reduction
	Moderate fuel intensity reduction
	Vehicle downsizing
	Low resistance tyres
	Gross polluter control
	Accelerate fleet turnover
Price signals	Higher oil prices (comparison scenario)
	Urban road pricing
	Increased urban parking charges
Mode shift	Urban car travel to UPT
	Urban car trips less than 1 km to walking
	Urban car trips less than 10 km to cycling
	Road passengers to rail travel
	Road freight to rail
	Road freight to coastal shipping
	Rail freight to coastal shipping
Freight efficiency	Larger combinations (such as B-triples) than B-doubles
	Engine efficiency improvements
	Lower rolling resistance
	Regenerative braking
	Larger PBS trucks
	Improved logistics
	Central logistics
Domestic shipping	Bio-diesel/hydrogen
	Ship efficiency improvements
	LNG
Domestic aviation	Alternative fuels
	Aircraft technologies
	Airline industry logistics / air traffic management
Transport management	Traffic management
Alternative fuels	Natural gas
	LPG
	Biodiesel
	Ethanol
	Electric light vehicles
	Electric heavy vehicles
Travel reduction	Telecommuting

Transport infrastructure	Improved road materials
	Pavement design
	Optimising asset use
Urban design/planning	Co-location and connection enhancement

Within Workshop 2, the various category options were assessed in terms of:

- whether there was general agreement on the size of the proposed adoption rate values
- whether appropriate assumptions/inputs had been used in the modelling and estimation procedures
- how key knowledge gaps or uncertainties might affect the calculations and thus impact on each option's scale/position on an overall abatement curve.

Participants were also asked to consider possible co-benefits and caveats for each abatement category and option, and to provide further information on likely challenges to be faced. Additionally, a scenario mapping exercise was conducted – which attempted to group sets of related options into possible chains of synergistic or complementary processes/instruments. Of course, as was well-recognised by the Workshop, this process is complicated by some options being purely abatement opportunities (that is, actions which physically reduce emissions), whilst others could be considered 'enablers' of such opportunities (that is, processes or signals which provide the incentives for actions to be adopted).

With this scenario-setting process, the Workshop came to identify as crucial that the various connections between the options (e.g. cross-links in required implementation paths or overlaps in resulting abatement effects) be considered and suitably assessed. Issues discussed that were considered vital to the final reporting task revolved around:

- clarifying pre-conditions (i.e. identifying circumstances necessary for a particular option to actually come about)
- avoiding double counting of options' total abatement (especially when two or more measures focus on the same transport activity or market)
- allowing for some abatement options having a higher level of certainty than others (either in likelihood of actually being enacted or in likely emission abatement potential and cost-effectiveness)
- recognising that various abatement options will require more or less enabling events, such as changes in public policy, than others.

Such discussions focused attention on the need to suitably aggregate the set of options into a possible transport sector *total* abatement (as well as assessing the potential of each option separately), given the wide overlap between the action of many of the options.

Overview of Workshop 3

Between Workshop 2 and Workshop 3, a draft summary document and technical report were completed and provided to the expert group. Participants were asked to provide feedback on these reports. The reports were assessed in detail, and the feedback was used to improve the assumptions, design, structure and key messages of the final report.

Prior to Workshop 3, the Project Secretariat concentrated on investigating how the greenhouse gas abatement options interact when combined. Since directly summing all the individual abatement potentials of the various measures does not give a meaningful answer (in fact, totalling almost twice the whole transport sector's base case emission projection for 2050), substantial care has to be taken when aggregating the effects of several options (especially to prevent double counting of emission reductions when the areas influenced by different options overlap).

For Workshop 3, a revised package of measures was developed – incorporating the main transport abatement opportunities assessed throughout Workshops 1 and 2 – with a view to estimating the combined impact of all the feasible options by 2050. As well as presenting updated and revised versions of the individual impact assessments for each option, Workshop 3 also introduced an 'Aggregate Scenario' which evaluates the maximum abatement by 2050 from the chosen options all acting together.

Workshop 3 reviewed the 2050 abatement estimates, including the assumed adoption fractions for each option, the transport sub-sectors or markets likely to be most affected by each option, the future emission levels due to those markets/activities, and the estimated savings fraction each option could apply to its market. The review considered the options individually (as stand-alone alternatives) and as part of the aggregate package of measures (allowing as much as possible for their likely interactions and overlaps).

Abatement calculation methodology

This Technical Report provides background information on the calculation processes for each of the chosen options – giving estimates for the individual 2050 abatement potentials and for the respective contributions to the Aggregate Scenario' s total 2050 abatement across the transport sector. The final list of options evaluated – for both individual and aggregate abatement – is given in Table 4.

This list of transport options is not meant to be exhaustive or prescriptive, and does not claim to cover every single emission abatement measure worthy of consideration. It merely aims to contain a reasonable sample of the abatement opportunities likely to be available within the transport sector over the coming decades, and to be roughly representative of maximum potential abatement from an integrated package of transport sector options.

When combining the options, using the chosen accumulation methodology (where each preceding option's abatement reduces the amount of emissions for the other proceeding options to act upon) – so as to derive a more realistic indication of their summed or aggregate potential impact – one analytical complexity introduced was that an order of evaluation had to be chosen.

The ordering of the options selected for the Aggregate Scenario evaluation is that shown in Table 4 – and again is not meant to be prescriptive. The current ordering of the individual options in Table 4 is fairly arbitrary, and just reflects the computation sequence chosen for the aggregation process (where the category with the largest aggregate abatement potential – Vehicle and Fuel Technology – was selected to be first in the evaluation). Changing the order of the options would not alter the derived aggregate abatement across the full transport sector, just the components of that total abatement calculation, estimated during the aggregation process.

For example, for those options chosen to be at the head of the Table 4 list, their 'in sequence' abatement estimates will typically appear to have a greater impact on aggregate abatement than those that appear later in the list – since the 'residual market' (i.e. the emissions remaining, within a particular transport activity or market sector, once the options above have produced their relevant level of abatement) for an option is reduced for each proceeding step in the aggregation sequence. If an option were to be moved down the evaluation list, its resulting 'in sequence' abatement estimates would tend to reduce, and any options moved up the list would typically have their 'in sequence' abatement values increase accordingly.

The 'in sequence' abatement for any particular measure is thus generally not all that meaningful – and to gauge the actual abatement potential of an option one has to look at the 'individual' (or stand-alone) abatement values – yet the various 'in sequence' estimates are provided in this report so that interested readers can roughly follow the calculation of the option combination/aggregation process.

Having assembled the list, each option was assessed using a straightforward framework, shown in the following example, and given here to demonstrate the basic layout of the Technical Report's data assessment tables.

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)

Estimated 'Individual' abatement potential

Vehicle technology	Regenerative braking	0.90	Urban rigids	9.1	0.20	1.6

'In sequence' calculated contribution to aggregate abatement

Vehicle technology	Regenerative braking	0.90	Urban rigids	7.6	0.15	1.0

This calculation 'key' is reproduced from later in the report, from the section describing possible 2050 abatement from the introduction of regenerative braking to the Australian truck fleet. Such estimation/calculation details are provided in this Technical Report for each of the options listed in Table 4. The first two columns identify the abatement type or category (here vehicle technology improvements) and then the specific option being considered from within that category (regenerative braking). The third column, for the assumed 'adoption fraction' (here set to 0.9 for both 'individual' and 'in sequence' rows), says we estimate that 90 per cent of relevant truck fleets could employ regenerative braking by 2050. Note that the adoption fraction values given in these option assessment tables (in the following option detail sections of the report and in summary Tables 6 and 7) relate to ***net*** adoption of the abatement opportunity by 2050 – i.e. are relative to any adoption already assumed in the base case (e.g. if the base case scenario has 5 per cent of automotive diesel sales replaced by biodiesel by 2050, and the assessed option raises this level to 80 per cent of diesel sales, then the *net adoption* for biodiesel refers to the difference between these two sales levels)[3].

The relevant market affected by the option is given in the next column (here assumed to be primarily urban rigid trucks). The fifth column contains the estimates for 'market emissions' – that is, for the 'individual' abatement row, the 2050 base case emission projection for urban rigid truck use of about 9.1 megatonnes (where the base or 'reference' case emission projections are described in the following section). Note that all emission values are given here in terms of million tonnes of direct CO_2 equivalent (i.e. contribution of CO_2, CH_4 and N_2O) from the full fuel cycle (FFC, i.e. including upstream emissions from energy supply/conversion processes).

The 0.2 value in the next column (the 'savings fraction' cell for the 'individual' abatement row) is the proportional emissions savings estimated for that particular technology/option (i.e. each vehicle with regenerative braking is estimated to save about 20 per cent emissions relative to its baseline trend). The final column ('2050 Abatement' for the upper 'individual' row) then shows the result of the abatement potential calculation: how many million tonnes of CO_2 equivalent per year can be abated relative to the baseline trend – in this case around 1.6 Mt per year by 2050 – by this option acting in isolation. The number in this column is essentially the result of multiplying the numbers in three other columns – i.e. the 'adoption fraction' times the 'market emissions' times the abatement 'savings fraction'.

As mentioned earlier, each option's descriptive details also include the lower row of calculations – giving the option's contribution to that aggregate abatement estimate. For this truck regenerative braking example, the relevant 'market affected' (urban rigid trucks), does not have the same 'market emissions' value for the 'in sequence' calculations as in the just-described 'individual' abatement row - since it no longer refers to the *base case* emission value for that transport activity, but the *residual market* value (i.e. the remaining emissions after other options higher in Table 4 sequence have been applied to the base case value).

In this example, the base case emission projection for urban rigid activity, of 9.1 Mt CO_2e in 2050, has been reduced by the truck options above 'regenerative braking' in the Table 4 listing (i.e. enhancing truck engine efficiency and reducing average rolling resistance). The resulting estimate for the size of the 'market emissions' cell for the 'in sequence' row therefore becomes 7.6 Mt CO_2e in 2050. For this example, the assumed 'savings fraction' for the 'in sequence' row has also been reduced from the 'individual' calculations – to allow for some of the potential energy gains (considered in isolation) from such technology to be already obtained by various technologies introduced by the options higher in the aggregation list. The resulting 'in sequence' aggregate abatement contribution thus becomes 0.9 times 7.6 times 0.15, or approximately 1.0 Mt CO_2e estimated for 2050 (emission reduction relative to the base case).

This general assessment framework has been applied to all 47 options listed in Table 4 – with the details of each option's abatement estimates provided later in this report (following the order listed in Table 4).

[3] That is, various options already partially figure within the reference case trends, (such as an option which does not contemplate the introduction of a totally novel technology or behavioural change, but envisions increasing the use or fleet penetration of some feature assumed to gain partial market share over time even under 'business-as-usual' conditions), and so the '2050 abatement' estimate has to be proportionately reduced (i.e. to allow for the difference between the amount of adoption assumed in the ALCTF scenario and that assumed in the base case scenario).

Table 4: Package of measures for Workshop 3: Order of evaluation for Aggregate Scenario

1. VEHICLE AND FUEL TECHNOLOGY	
Light vehicles	Electric/plug-in cars
	Fuel super-efficiency
	Downsizing
	Bio-fuels
Trucks	Engine efficiency
	Low rolling resistance
	Regenerative braking
	Electric trucks
	Biodiesel
Aviation	Technology
	Bio-fuels
Maritime	Technology
	Bio-fuels
Rail	Technology
	Bio-fuels
Bus	Technology
	Electric buses
	Bio-fuels
2. PRICE SIGNALS	
Variable prices	Road/congestion pricing
Pay-As-You-Drive fees	Distance based charges (e.g. For registration and insurance)
Commuter charges	Extra parking charges
3. REGULATION	
Light vehicles	Moderate fuel efficiency standards
Trucks	Large combinations such as B-triples
	PBS trucks
All road vehicles	Gross polluter control
4. URBAN TRANSPORT	
Urban vehicle demand	Urban form/design
Urban Public Transit (Rail/bus)	Telecommuting
Light vehicles	Travel demand reduction, including telecommuting
	Mode shift car-UPT
	Mode shift car-walk
	Mode shift car-cycle
	Mode shift car to velomobiles and power-assisted cycling
	Eco-driving

5. INFRASTRUCTURE	
Hard	Pavement design
	Pavement smoothing
	Improved pavement materials
Soft	Airspace management
	Traffic management
	UPT priority + information systems
6. FREIGHT / HEAVY VEHICLES	
All freight	Mode shift, road-rail
	Mode shift, road/rail-sea
	Improved logistics
Trucks/buses	Eco-driving
7. OTHER	
Aviation	Telecommuting
Rail	High Speed Rail, replacing some aviation demand

Since the abatement estimates are not calculated relative to current emission levels or fuel intensities, but in relation to 2050 projections under a 'base case' scenario (or *reference* trend) for the future, the particular specification of that base case scenario has a significant bearing on the resulting abatement calculations. Any technological prospect assumed to achieve substantial future market share even under business-as-usual trends (and thus already incorporated into the base case scenario) may have only a slight 2050 extra 'abatement potential' estimated for it (i.e. relative to that base case) even if offering large efficiency gains relative to current practices.

Given the importance of the base case specification to the abatement estimation process, the next section presents a summary of the base case projections of domestic transport sector activity. This base case has been developed by the Bureau of Infrastructure, Transport and Regional Economics by adapting their previously published projections (BITRE 2010).

Base case emission trends

The base case emission trends used for the ALCTF analyses are described in the BITRE report *Long-term Projections of Australian Transport Emissions: Base Case 2010* (BITRE, 2010). This report, prepared for the Department of Climate Change and Energy Efficiency (DCCEE), presents the results of a detailed study by BITRE into the modelling and forecasting of greenhouse gas emissions from the Australian transport sector.

The report, whose contents are briefly summarised here, (and available on the DCCEE website at: http://www.climatechange.gov.au/publications/projections/~/media/publications/projections/bitre-transport-modelling-pdf.pdf) forms the basis for the transport component of the Government's most recent official projections of Australian greenhouse gas emissions (such as released periodically as part of Australia's *National Communication on Climate Change* reports (DCCEE, 2010) under the United Nations Framework Convention on Climate Change). The 2010 projections provide Australia's current baseline emissions for the Kyoto Protocol first commitment period and out to 2020, as well as providing the basis for estimating the likely 'abatement challenge' Australia faces in meeting its medium to longer term emission reduction targets.

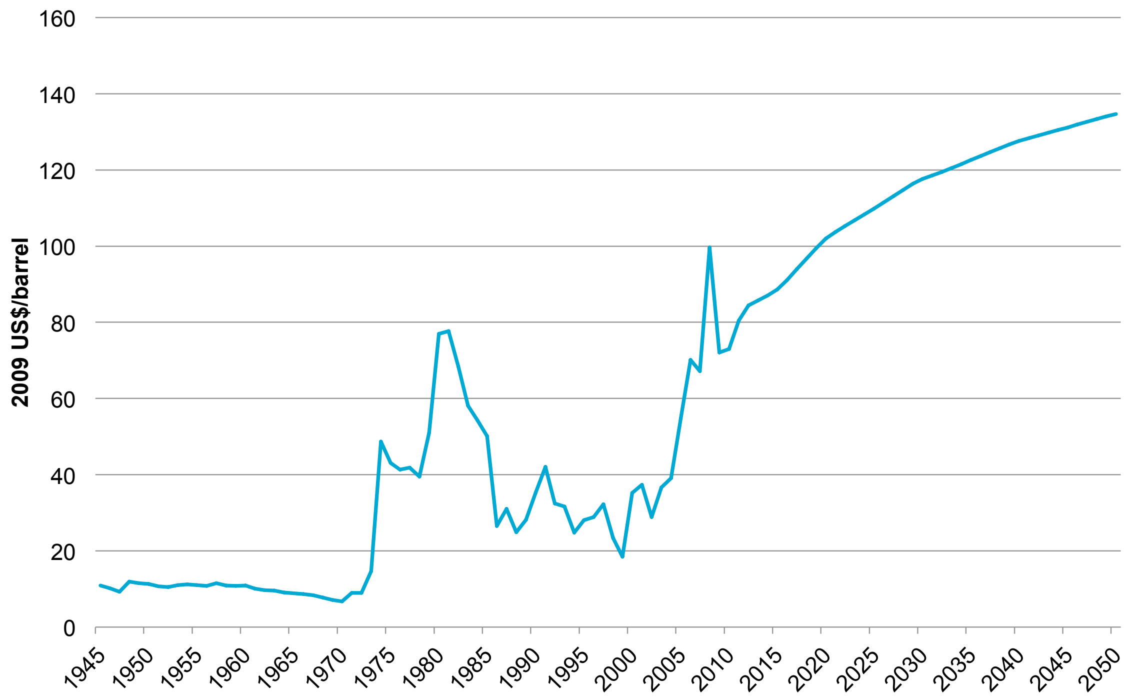
The '*base case*' or *reference* scenario emission projections described here are estimated using primarily 'business-as-usual' (BAU) assumptions for the coming years – i.e. based on current trends in major economic indicators and demography (with continuing growth in national population and average income levels, and only gradually increasing petrol prices), the scenario adopts what is considered the most likely future movements in travel behaviour and vehicle technology. DCCEE reference scenario specifications could be more fully described as a '*base case with measures*', in that such a scenario also incorporates the impact of the likely progress, over the medium term, of various greenhouse gas abatement measures that Australian governments have already implemented or fully framed.

A number of inputs have been considered for the base case. These include aggregate inputs, energy use and efficiency trends, task saturation trends, aggregate task projections, modal emission projections and indirect emission effects.

Aggregate inputs

Reference scenario inputs were provided by Treasury for major economic (real Gross Domestic Product and national employment parameters) and demographic (national population levels and proportion of working age) trends – with data provided by Treasury consistent with the Pre-Election Economic and Fiscal Outlook (PEFO) 2010 (Treasury 2010b) and Intergenerational Report (IGR) 2010 (Australia to 2050: future challenges, Treasury 2010a). The population projections in IGR 2010 are roughly in line with previous mid-range projections released by the Australian Bureau of Statistics (ABS), with national values for 2050 falling roughly midway between those for ABS trend 'Series A' and 'Series B' in *Population Projections, Australia* (ABS, 2008, Cat. No. 3222.0). The base case projections have national population reaching almost 26 million persons by 2020 and about 36 million persons by 2050.

Future values for another major base case input, crude oil prices, were based on extrapolations of reference scenario trends given in the International Energy Agency's *World Energy Outlook 2009* (IEA 2009a). See Figure 3 for the oil price assumptions incorporated in the base case scenario.



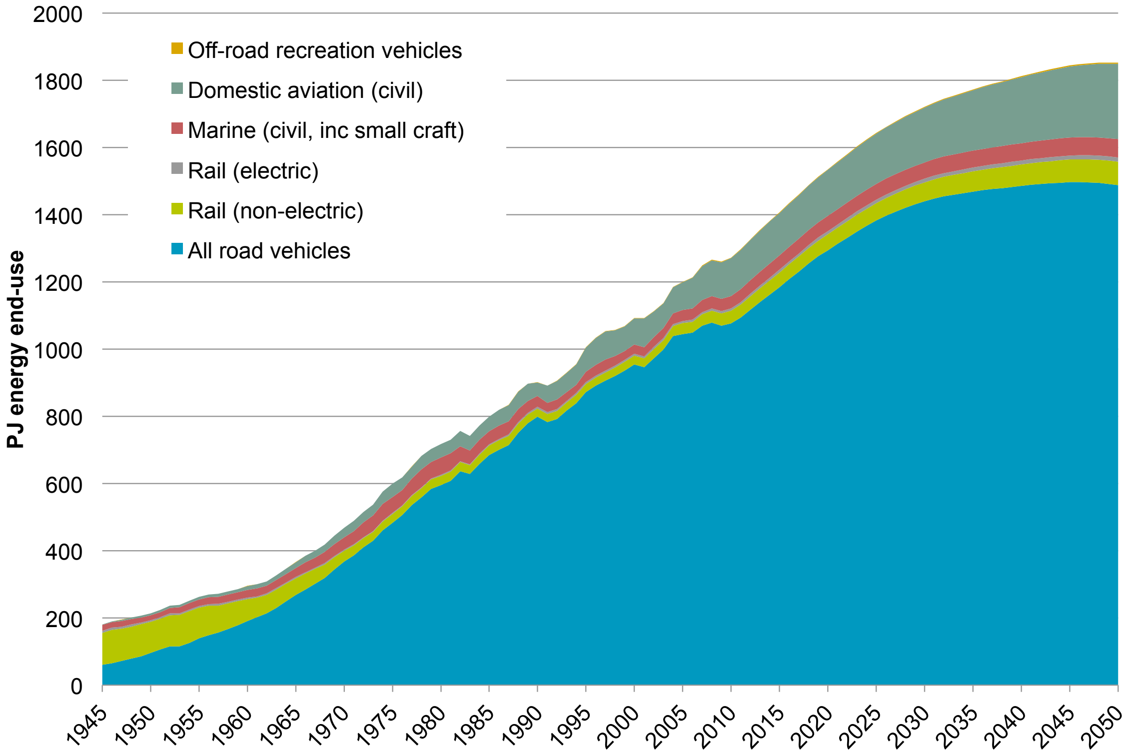
Sources: IEA (2009), BITRE (2010).

Figure 3: Projections of crude oil prices for the base case scenario.

Energy use and efficiency trends

BITRE studies have investigated long term historical trends (from the early 1900s to the present) in Australian transport tasks and the resulting fuel consumption patterns, to gain a fuller understanding of possible travel behaviour responses (e.g. to factors such as price and income changes) and movements in modal energy efficiency. The resulting energy consumption estimates from the BAU modelling, displaying both the *long term historical* trends (1945 to 2010 financial years) and the extension of the Base Case 2010 projections over the *longer term future* (out to 2050, based on structural task trends identified by the BITRE *TranSaturate* model) are shown in Figure 4 (for energy end-use by mode for Australian civil domestic transport) and Figure 5 (for energy end-use by fuel type for Australian civil domestic transport). The split of this energy use by vehicle type, for all road vehicles, is given in Figure 6.

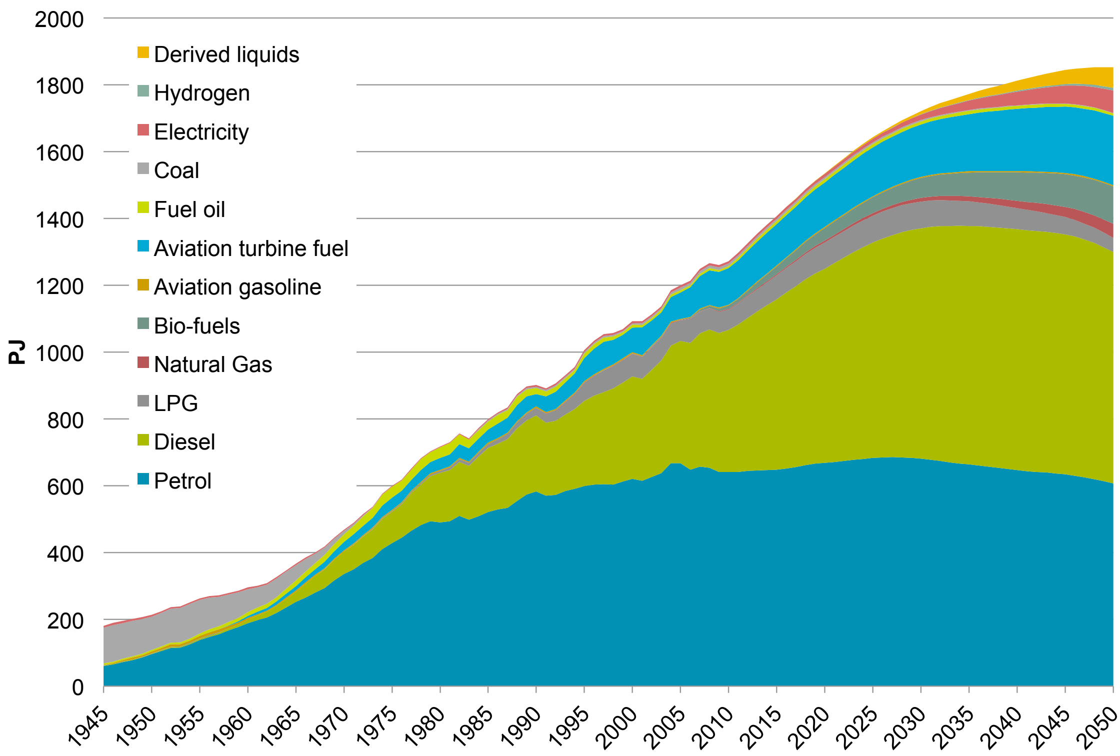
Under the BAU scenario assumptions, expected increases in overall energy efficiencies serve to roughly stabilise aggregate end-use consumption from about 2040 on. Figure 5 presents an *indicative* fuel mix scenario over the projection period – that is, one possible composition of the future transport fuels market, given current assumptions about likely prices and availability of the various fuel alternatives (and the respective vehicle technologies that use those fuels). Note that the resulting fuel mix is highly sensitive to the scenario input assumptions (e.g. concerning likely cost paths of both fuel production and engine innovation), and to possible policy developments (such as could relate to vehicle regulation, industrial subsidies or externality charges).



Source: BITRE (2010).

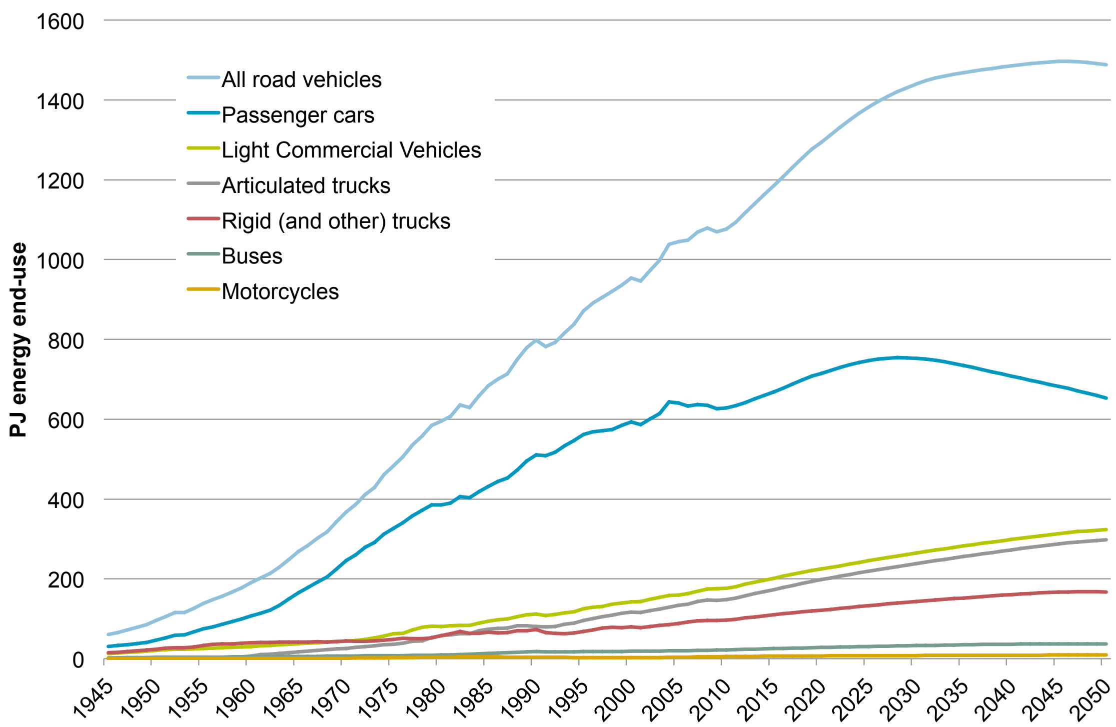
Figure 4: Energy end-use by mode for Australian civil domestic transport, base case projections.

The fleet modelling for the base case features gradual energy efficiency improvements, for most transport activities, over the projection period – with the historical and projected BAU emission intensity reductions shown in Figure 7 for freight tasks (in terms of grams of direct, full fuel cycle CO_2 equivalent per tonne-kilometre performed) and Figure 8 for passenger movement (in terms of gCO_2e per passenger-kilometre).



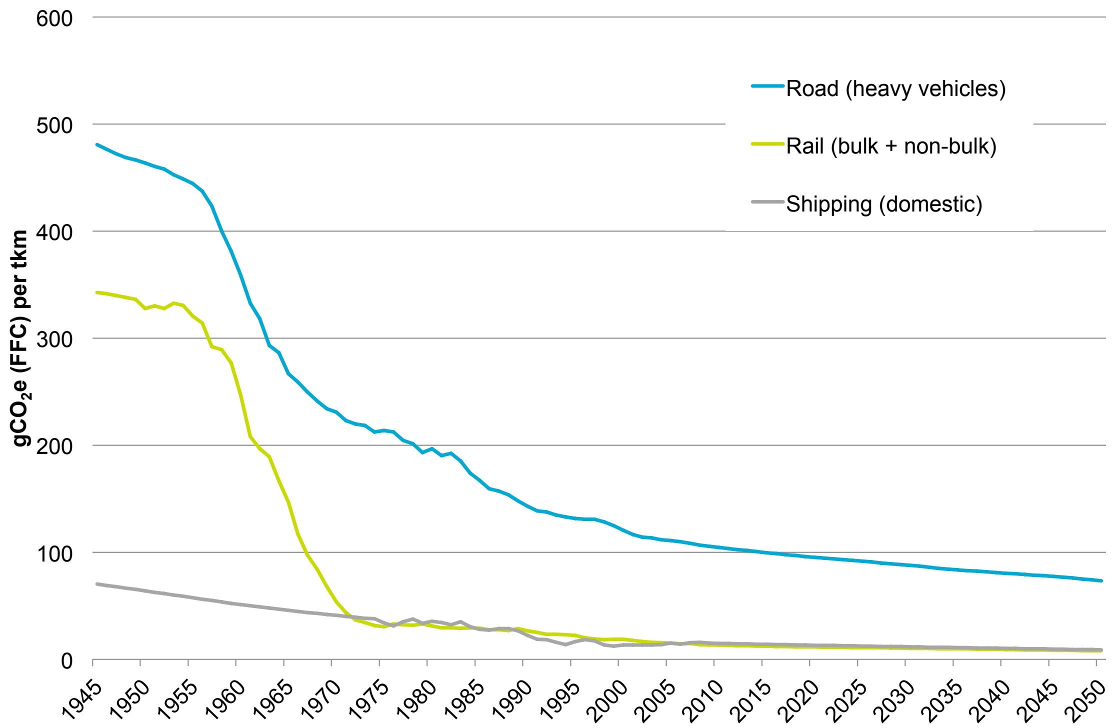
Source: BITRE (2010).

Figure 5: Energy end-use by fuel type for Australian civil domestic transport, base case projections.



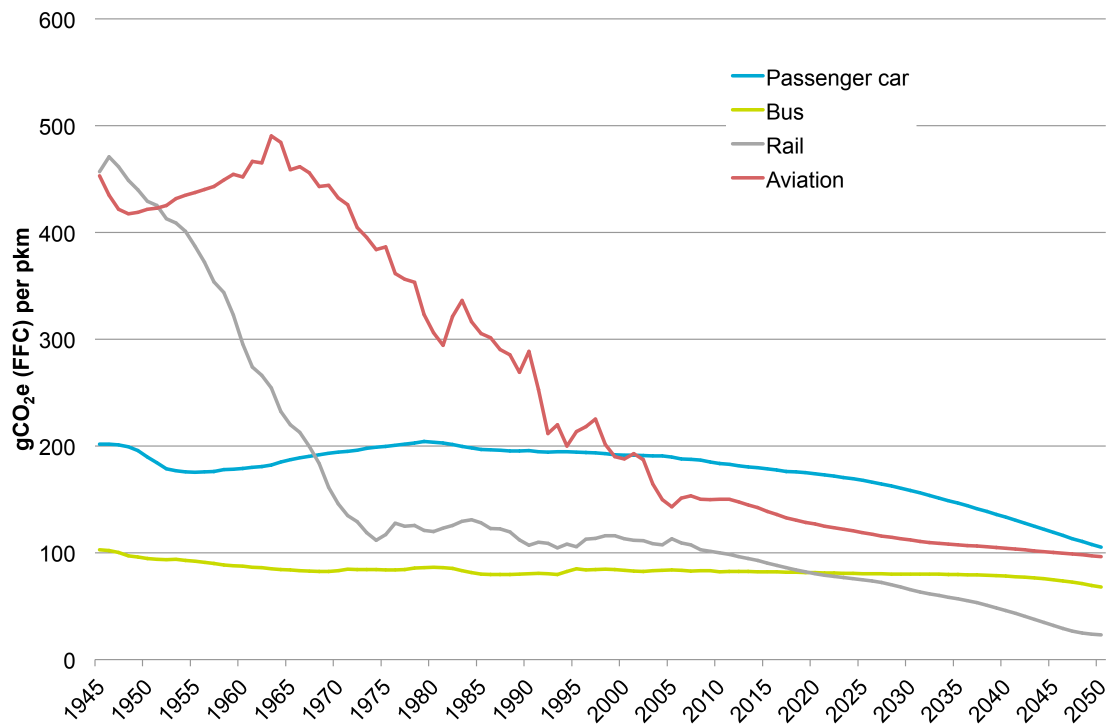
Source: BITRE (2010).

Figure 6: Energy end-use by vehicle type for Australian road transport, base case projections.



Source: BITRE (2010).

Figure 7: Freight emission intensity by mode, base case projections for average operating conditions.



Source: BITRE (2010).

Figure 8: Passenger emission intensities, base case projections for average operating conditions.

Task saturation trends

Along with these underlying trends towards improved vehicle or engine energy efficiency, the other main factor behind the general slowing of annual growth in transport energy consumption. Apparent in Figure 4, is a tendency towards eventual saturation levels for per capita travel.

There is a wide range of underlying factors that influence growth in transport demand (and in consequent transport energy consumption and transport emission levels). The main drivers (or generators) behind the strong historical growth in total Australian passenger travel (as well as behind the significant growth in travel by private road vehicles) have tended to be increases in population and increases in per capita daily travel. The latter trend increase has principally been the result of rising per capita incomes, typically allowing greater choices in residential location, mode choice, and trip selection – and also higher potential travel speeds, as road networks have developed over time. Rising national income levels have also been strongly tied to growth in the amount of freight transported.

Demographic effects (including changes to land-use, urban form, or city density patterns) can also be important with respect to how much daily travel increases; especially with the historical tendency for Australian cities to grow ever outwards (as the demand for increasing levels of residential living space has typically lead to more and more greenfield developments), often leading to longer average trip lengths.

People's transport choices will furthermore depend on a variety of other attributes – 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, the cost of vehicles or bus fares, but also in a more generalised sense, such as the travel time limits imposed by traffic congestion delays. Similarly, the choice of a mode for freight movement will not depend solely on direct costs, such as freight rates, but will also be affected by such factors as the timely delivery required by perishable commodities.

For many years, Australia has seen the complex interplay of all these underlying effects lead to steadily increasing levels of both personal mobility and the distribution of goods and services – particularly in parallel with the wider availability of motor vehicles. With the resulting historical trend of increasing transport task levels, Australian passenger travel (in terms of domestic passenger-kilometres performed) has grown almost ten-fold over the last 60 years, and domestic tonne-kilometres by nearly 17 times – along with the mode shares of motor vehicles generally increasing for decades.

An important relationship underlying BITRE projections of these historical task trends into the future concerns the connection between rising income levels and per capita travel.

Figure 9 plots over six decades of per capita passenger task estimates, for Australian urban travel, against the average income level at which the aggregate transport activity was undertaken. Note how markedly the growth rate in pkm per person has reduced in recent years (right-most points on the Figure 9 data curve), especially compared with past very high growth in per capita travel (i.e. for values towards the left-hand side on the curve, roughly corresponding to the 1950s to 1970s).

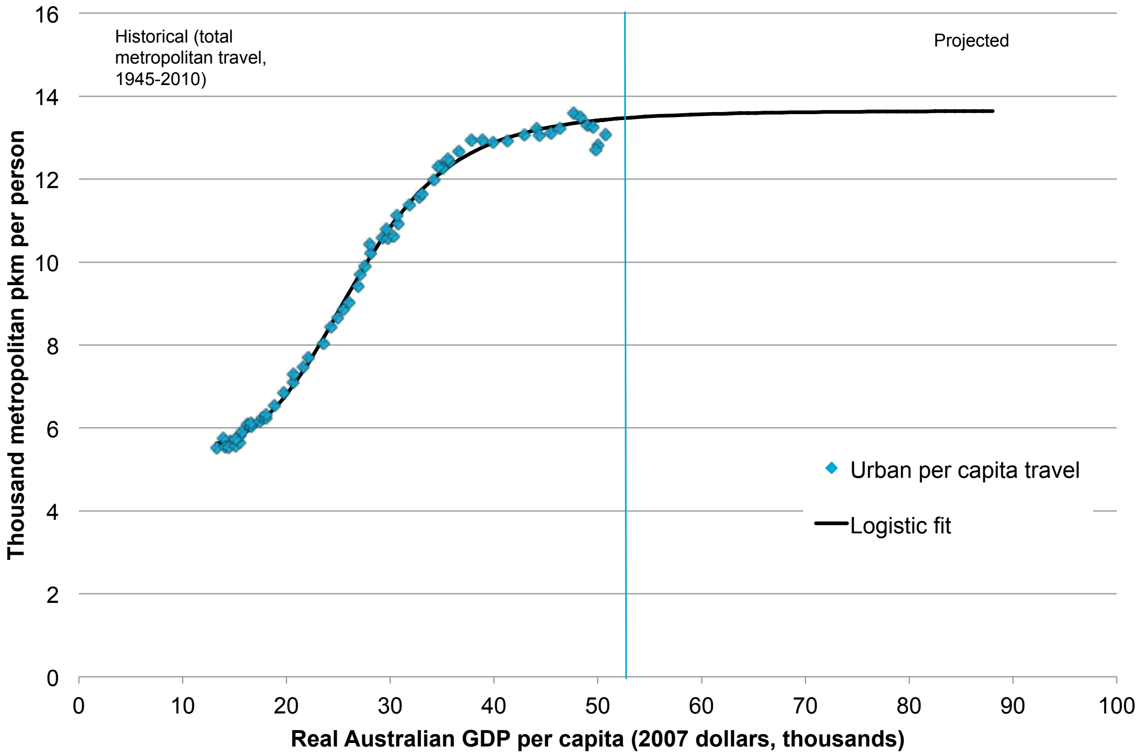
As income levels (and motor vehicle affordability) have tended to increase over time, average travel per person has increased. However, there are constraints on how far this growth can continue. Eventually, people are spending as much time on daily travel as they are willing to commit, and are loath to spend any more of their limited time budgets on yet more travel, even if incomes do happen to rise further. Therefore, future increases in Australian urban passenger-kilometres travelled are likely to depend more directly on the rate of population increase, and be less dependent on increases in general prosperity levels.

Figure 9 also gives the resulting (logistic) curve fit for the underlying trend in (latent) per capita urban passenger movement (where the x-axis uses per capita real Gross Domestic Product, in thousands of 2007 Australian dollars, as a proxy for national average income levels). This saturating relationship suggests that an upper bound to per capita urban travel could effectively apply to Australia within the next decade or so.

Such curves can be fit individually for each of the major Australian passenger tasks, with somewhat differing saturating trends. With such asymptotic or limiting behaviour being identified within the time-series data for most short-distance travel, the implication is that growth in per capita daily travel is likely to be lower in the future than for the long-term historical trend.

The (per capita) pkm versus income curve for long-distance travel does not, however, exhibit as strong a slowing in annual growth as found (and plotted in Figure 9) for urban daily travel, due to continuing strong growth in air travel (with its inherent advantages in reducing travel time spent per kilometre). Still, with growth in short-distance travel per capita slowing markedly in recent times, 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.

Note that this decoupling of income levels from personal travel trends is not yet apparent in the current freight movement trends. Average tonne-kilometres performed per capita are still growing quite strongly – and even though the freight trend curve is slightly concave, there is no strong saturating tendency evident for the near future. The freight trend curve will presumably have to shallow off too, over the longer term, but there is no sign of it occurring over the short-term. Growth in freight and service vehicle traffic is therefore expected (over at least the next decade or so) to be substantially stronger than for passenger vehicles (e.g. see Figure 6).



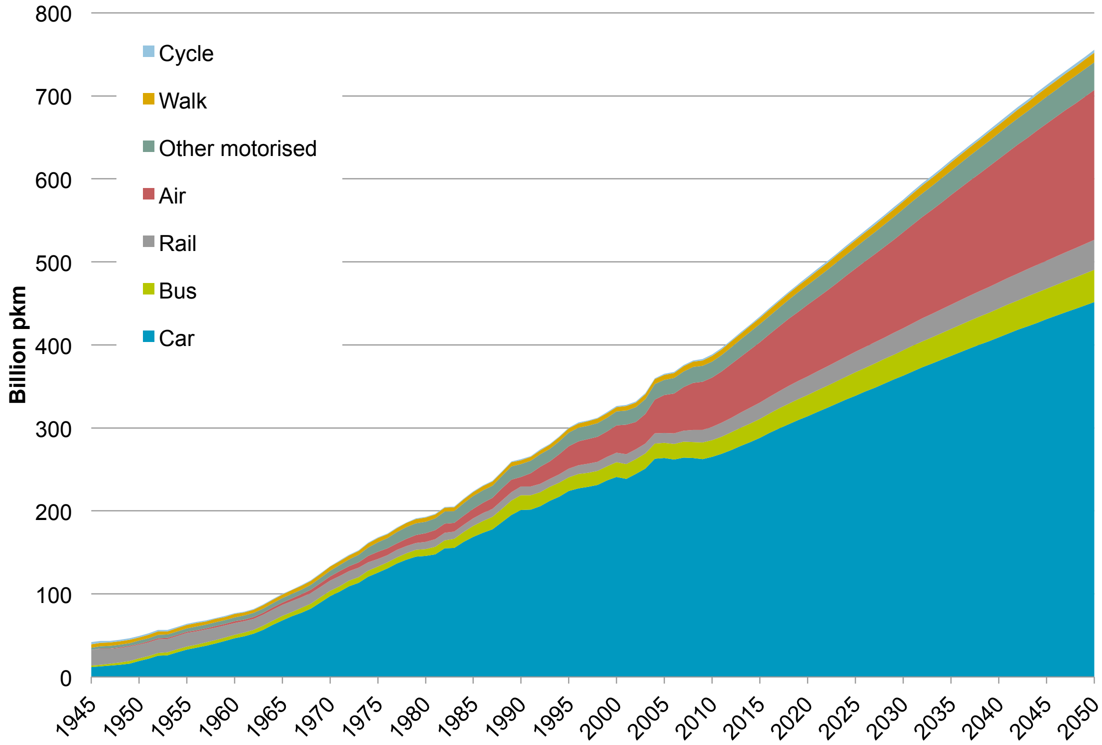
Source: Cosgrove (2011).

Figure 9: Relationship of per capita Australian urban travel to per capita income.

Note: For each data point: y-axis value refers to total annual passenger travel (in pkm) within the State and Territory capital cities, divided by the resident metropolitan population (as at each year ending 30 June, totalled across the capital city Statistical Divisions); x-axis value refers to average Australian income level, calculated here as real national GDP for the relevant year (ending 30 June), divided by the national population level.

Aggregate task projections

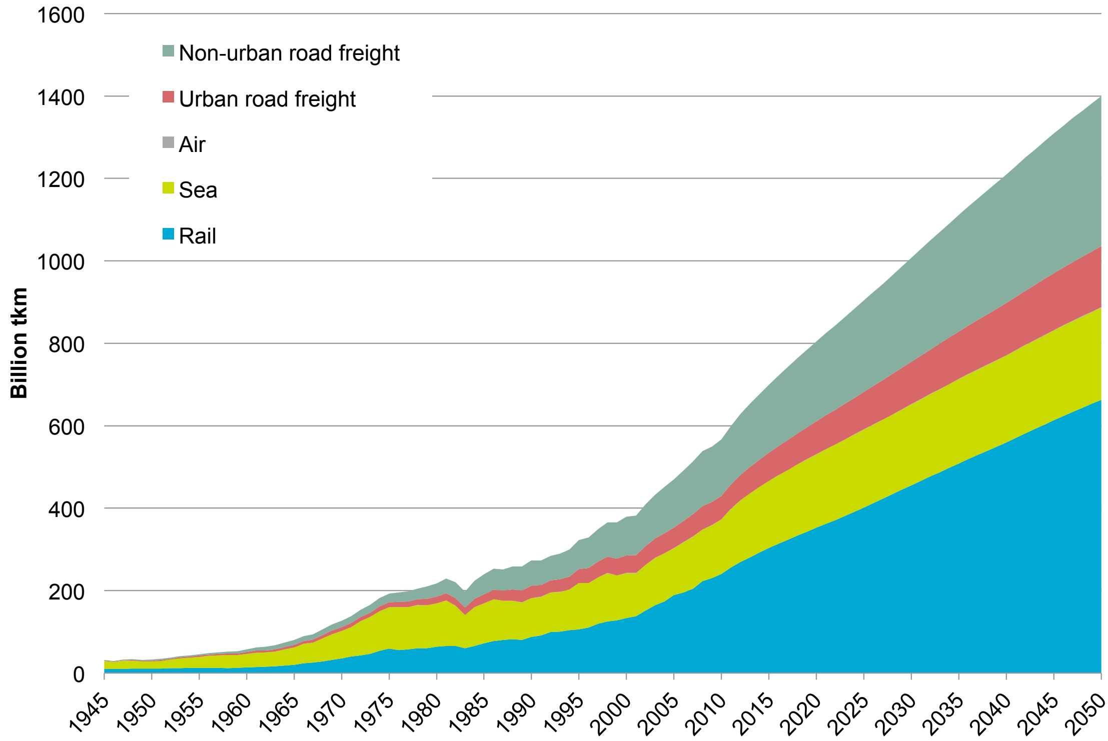
The various modal task projections result in the base case aggregates for passenger travel trends (shown in Figure 10) and freight movement to 2050 (see Figure 11).



Source: BITRE (2010).

Figure 10: Long-term trends and base case projections for total passenger tasks, Australian civil domestic transport, motorised and non-motorised.

Notes: 'rail' includes both train and tram travel. 'Other motorised' primarily consists of non-business use of light commercial road vehicles, with contributions from motorcycles, trucks and ferries.

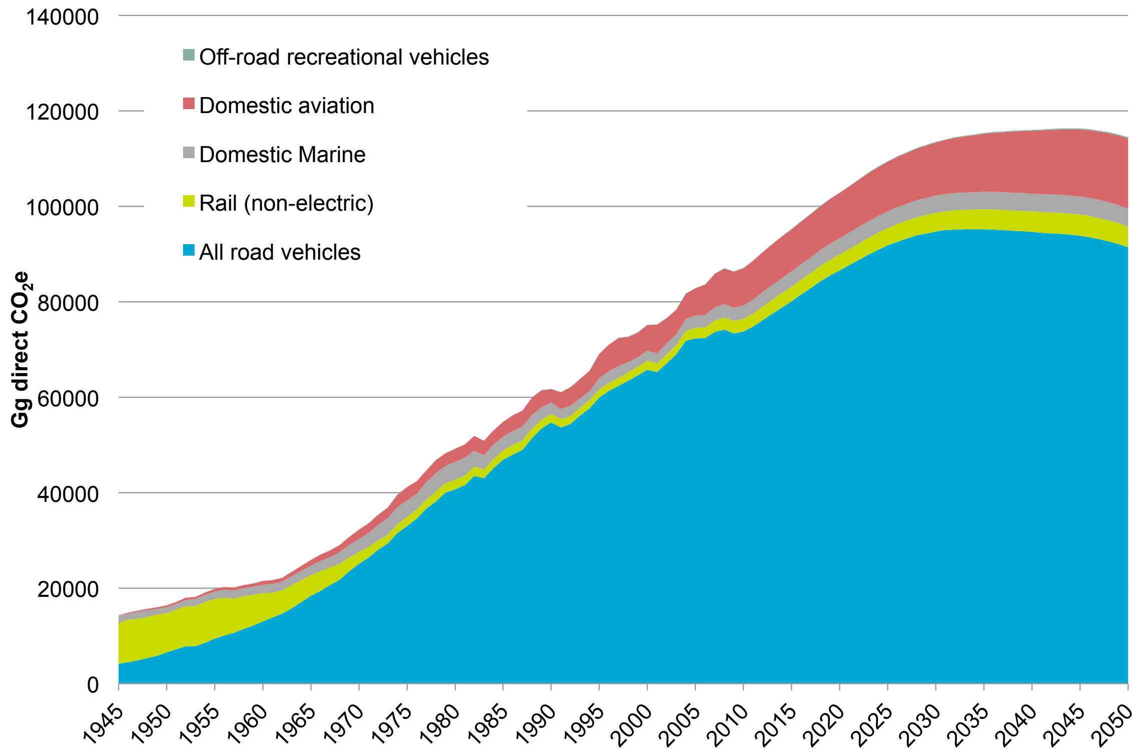


Source: BITRE (2010).

Figure 11: Long-term trends and base case projections for aggregate Australian freight movement.

Modal emission projections

Transport sector end-use emissions are given in Figure 12 (where Gigagrams, Gg = 10^9 grams, equivalent to thousand tonnes). They use the sectoral accounting framework of the National Greenhouse Gas Inventory (NGGI) Commonwealth of Australia (2011c) - resulting from the base case energy projections displayed in Figures 4 and 5 (flowing from the task projections given in Figures 10 and 11, performed at the projected unit efficiency levels, as per Figures 7 and 8).



Source: BITRE (2010).

Figure 12: Long-term trends and base case projections for end-use emissions from Australian civil domestic transport, by mode.

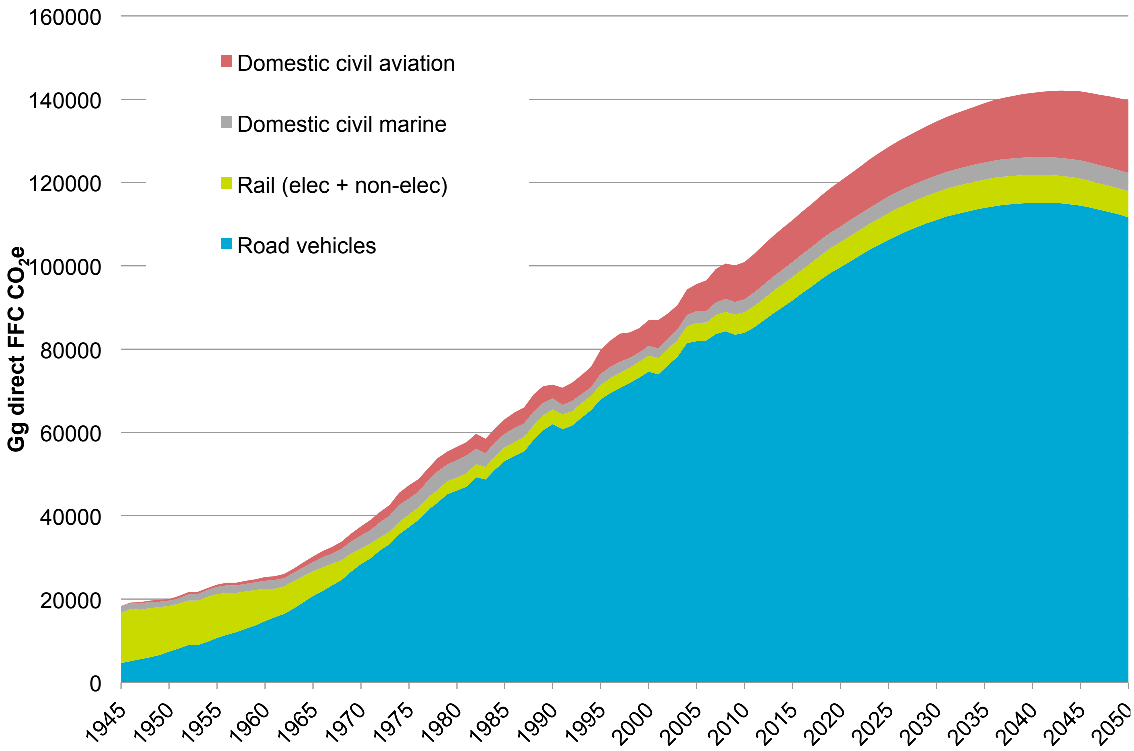
Notes: Emissions are direct greenhouse gas emissions only – carbon dioxide, methane and nitrous oxide (i.e. do not include indirect effects of gases such as the ozone precursors carbon monoxide and nitrogen dioxide); converted into CO_2 equivalent figures using NGGI-specified values for the Global Warming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

Emission estimates here relate to energy end-use (i.e. do not include emissions from fuel supply and processing, or from power generation for electric railways and vehicles); and, as specified by the NGGI, exclude CO_2 released from the combustion of biofuels.

Usage of 'Off-road recreational vehicles' is only roughly estimated. 'Aviation' includes emissions from general aviation. 'Marine' includes emissions from small pleasure craft and ferries, and from some fuel uplifted by international vessels but consumed undertaking a domestic shipping task. Emissions from fuel used by military transport (and by ancillary mobile engines; including fishing boats, off-road mine/quarry vehicles, lawn-mowers, industrial equipment such as forklifts and agricultural machinery) are excluded.

Since many of the options being assessed by the ALCTF involve possible changes to fuel supply, end-use emission values are not fully suitable for these analyses. For a more complete picture of total emissions due to the Australian transport sector, and to aid consistent modal comparisons (especially since end-use values do not include any of the emissions due to electricity use), estimates of full fuel cycle (FFC) emissions from transport activities are also derived. These are the values used in this report's analysis – where 'full fuel cycle' values refer to the inclusion of emissions released during transport fuel supply and processing, and during power generation for electric vehicles or railways, as well as from direct fuel combustion. The FFC values provided include net emission estimates for biofuel use (i.e. include allowances for likely emission levels arising from biofuel processing and due to feedstock provision, such as from fertiliser use and crop harvesting) – where such net results are necessary when trying to assess actual emission abatement from the market take-up of biofuels.

The FFC emission projections for the base case scenario, across the Australian civil domestic transport sector, are given in Figure 13 (and Table 5).



Sources: BITRE (2010), BITRE estimates.

Figure 13: Base case projections of full fuel cycle emissions from Australian civil domestic transport, by mode to 2050.

Notes: CO_2 equivalent emission values here include only contributions of direct greenhouse gases (CO_2, CH_4 and N_2O).

Full fuel cycle (FFC) estimates include emissions due to energy supply and conversion (e.g. from petroleum refining and from electricity generation). Net emissions for biofuels are also estimated (i.e. CO_2 emissions from the combustion of a biofuel are still discounted by the carbon captured during any biomass growth, but emissions due to the biofuel's production and the cultivation of its feedstock are also included here).

'Aviation' is all 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).

Totals plotted here would be slightly higher if off-road recreational vehicles were also included (currently roughly estimated to account for about 100-150 Gg per annum).

Table 5: Base case emission projections for Australian domestic transport *(gigagrams of direct CO_2 equivalent, FFC)*

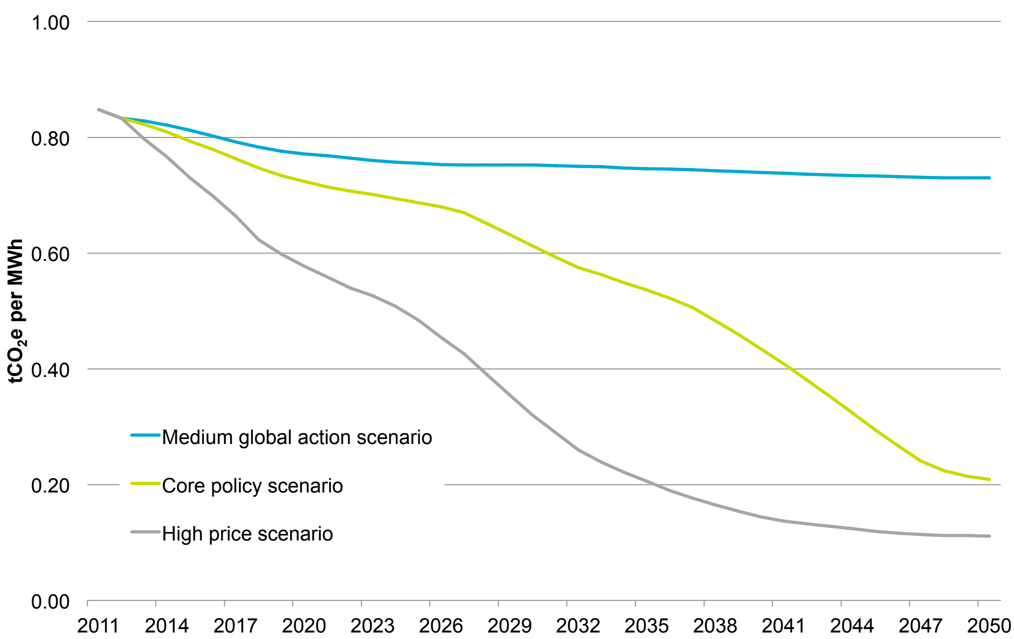
Fin. Year	Light road vehicles	Heavy road vehicles	Rail	Maritime	Aviation	Total
2010	62855	21101	4896	3147	8947	100945
2011	63590	21611	5091	3291	9276	102859
2012	64576	22337	5259	3399	9555	105126
2013	65605	22950	5400	3470	9763	107189
2014	66581	23548	5523	3534	9972	109158
2015	67526	24174	5614	3588	10085	110986
2016	68614	24806	5695	3634	10231	112980
2017	69681	25427	5766	3680	10356	114910
2018	70802	26035	5838	3726	10549	116949
2019	71798	26586	5912	3764	10712	118772
2020	72565	27095	5990	3801	10926	120377
2021	73382	27657	6070	3835	11084	122028
2022	74216	28229	6152	3868	11300	123764
2023	75019	28786	6237	3900	11534	125476
2024	75765	29303	6320	3926	11726	127041
2025	76443	29817	6403	3946	11912	128522
2026	77033	30320	6486	3963	12098	129898
2027	77549	30828	6554	3979	12265	131175
2028	78000	31346	6589	3997	12489	132420
2029	78357	31854	6621	4016	12710	133558
2030	78656	32361	6646	4035	12925	134623
2031	78934	32843	6668	4058	13156	135658
2032	79104	33288	6693	4080	13383	136548
2033	79204	33696	6736	4102	13659	137397
2034	79255	34152	6772	4123	13932	138233
2035	79287	34587	6806	4144	14201	139025
2036	79252	35024	6833	4164	14465	139738
2037	79151	35443	6847	4183	14722	140346
2038	78940	35837	6830	4201	14976	140785
2039	78719	36250	6813	4218	15225	141224
2040	78416	36645	6776	4234	15467	141539
2041	78085	37024	6743	4255	15702	141809
2042	77687	37375	6695	4275	15929	141960
2043	77259	37703	6640	4294	16147	142043
2044	76751	37992	6575	4311	16358	141987
2045	76219	38241	6505	4327	16558	141851
2046	75567	38437	6432	4341	16748	141524
2047	74844	38597	6358	4354	16926	141079
2048	74184	38713	6311	4364	17093	140665
2049	73525	38784	6288	4372	17246	140214
2050	72862	38795	6267	4367	17385	139677

Sources: BITRE (2010), BITRE estimates.

Notes: Emission estimates for carbon dioxide relate to full fuel combustion of carbon, with typically a 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 full fuel cycle (i.e. include emissions from fuel supply and processing, and from power generation for electric power). 'Light Road Vehicles' include all passenger cars (inc. Sports Utility Vans), Light Commercial Vehicles and motorcycles. 'Heavy road vehicles' include all trucks (rigid and articulated) and buses. 'Aviation' includes emissions from general aviation. 'Maritime' includes emissions from small pleasure craft and ferries, and from some fuel uplifted outside Australia but consumed by vessels undertaking a domestic shipping task. Emissions due to military transport are excluded.

Note that even though the end-use emission values displayed in Figure 12 are identical to the end-use values given in the BITRE (2010) report to DCCEE, the FFC values in Figure 13 are slightly lower than the FFC results provided in that report. This is due to differing assumptions between the two FFC evaluations concerning electricity generation emissions.

At the time of the preparation of the Base Case 2010 projections (BITRE 2010), the Government's Clean Energy Legislative Package had not yet been finalised or enacted – so the upstream energy factors in the original analysis did not include the possible effects of national carbon pricing on the electricity generation sector [4]. Since that time, Treasury has released modelling on the expected impacts of the proposed carbon pricing scheme (published in *Strong Growth, Low Pollution*, Commonwealth of Australia 2011a) – including estimates for the reducing carbon intensity of electricity generation probable over the coming years (as more renewable generation and other technologies serve to strongly de-carbonise the power supply sector). The de-carbonisation rate assumed in the Treasury 'core policy scenario' (Treasury 2011 modelling, see http://www.treasury.gov.au/carbonpricemodelling/content/default.asp, Figure 5.18 of Commonwealth 2011a) is reproduced here (as Figure 14 below).



Source: Treasury modelling, Commonwealth of Australia (2011a).

Figure 14: Forecast electricity generation emissions: tonnes of CO_2 equivalent per megawatt-hour delivered.

[4] Note that even though the Government has already announced its policy for upcoming mandatory carbon dioxide emission standards for new light vehicle sales, the details of this measure, at the time of this study, are yet to be finalised (i.e. the exact form, intensity and timing the measure will eventually take, along with some of the policy design elements, are still under consideration), and therefore the possible effects of such standards (on transport sector emissions) are not included in the current *base case* projections.

The base case FFC values have been recalculated for this report, applying revised upstream energy processing factors to the BITRE (2010) end-use results. Since the upstream emissions for future electricity end-use are substantially reduced within the Treasury core policy scenario, estimated FFC emission projections due to electric rail activity and electric/plug-in hybrid vehicles have been correspondingly reduced for this report. The FFC Base Case results for aggregate transport emissions used for the ALCTF comparative analyses (as provided in Figure 13 and Table 5) are therefore somewhat lower over the latter stages of the projection period (by about 3 per cent by 2050) than those provided in BITRE (2010) (as in that report's Figure ES.6, Figure 5.2 and Table 5.2).

Indirect emission effects

Another factor to consider when making use of the ALCTF results is that, for comparability purposes, the abatement values follow the usual current practice, and are given in terms of *direct* carbon dioxide equivalent (CO_2e) emissions.

That is, in accordance with current DCCEE/NGGI specifications for reporting of carbon dioxide equivalent values, the abatement calculations include only the effects of the directly radiative gases emitted from transport fuel combustion, comprising carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Such standard CO_2e values are estimated using reference Global Warming Potentials (GWPs) that DCCEE has specified for calculating inventory CO_2 equivalency for mass emissions of methane and nitrous oxide (i.e. 21 times for the amount of CH_4 emitted and 310 times for N_2O emissions, using a reference time horizon for warming effects of 100 years), taken from IPCC (1996; 1997) reports.

For many transport activities, 'CO_2 equivalent' greenhouse gas emission estimates would be significantly higher if the *indirect* effects of other gases emitted during combustion – particularly pollutants or ozone precursors such as carbon monoxide (CO), oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOCs) – were also taken into account. Most current climate-change conventions (such as the Kyoto Protocol) do not yet allocate GWP factors for indirect greenhouse gases, due to the difficulty in accurately quantifying global averages for warming from such 'indirect' greenhouse effects (i.e. the effects of atmospherically short-lived gases, like carbon monoxide, which are not radiatively active themselves but which can influence the concentrations of the directly radiative gases). However, the UN Framework Convention on Climate Change (UNFCCC) reporting guidelines encourage parties to the Convention to provide information on the emission volumes of various non-CO_2 gases – such as carbon monoxide, nitrogen oxides, non-methane volatile organic compounds, and sulphur oxides (SO_x) – especially for input into detailed climate models.

The application of GWP factors (to derive 'CO_2 equivalent' values) is not actually a concept used directly in climate modelling; the GWP is a simplified metric, primarily introduced as a way of quickly weighting the climatic impact of emissions of different greenhouse gases, in order to get a rough overview of their possible joint impacts. Ideally, appraisals of policy measures, in terms of their potential climate change impacts, should consider the total effects over the full transport system and its energy supply processes (including releases of all relevant gas species, from all relevant sources), not just CO_2 from fuel combustion.

These issues should be borne in mind when assessments are being made with regard to emission abatement estimates. Not only will calculated greenhouse gas emission levels (in 'CO_2 equivalent' terms) be higher if future climate-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 possible measures that promote the reduction of noxious non-CO_2 engine emissions, could also then be counted as greenhouse abatement measures). In particular, some of the options included in the ALCTF assessments would have even greater abatement potential than currently estimated using 'direct CO_2 equivalent' values (such as for the detection and repair of grossly polluting motor vehicles or for options acting on aviation demand – like teleconferencing – and aircraft technology[5]).

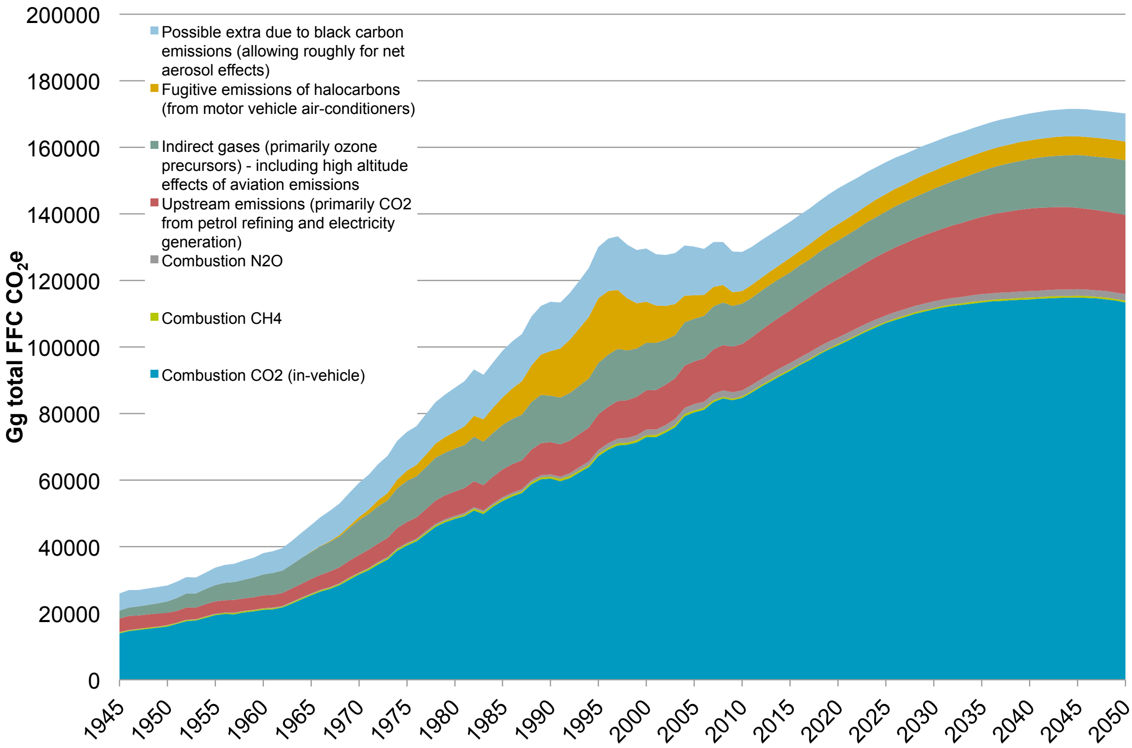
[5] The estimated differences would be especially significant for the aviation sector; due to the much greater warming impacts of certain aviation emissions when released at high altitude. The contribution of non-CO_2 effects to aviation's total radiative impact is judged to be considerable (see IPCC 1999) and the literature (e.g. Forster et al. 2006) appears to concur that adding indirect effects (especially of high altitude ozone and contrails) could give a total greenhouse contribution value for aviation roughly double that of the direct CO_2 emissions alone.

For information, this section provides some BITRE order-of-magnitude estimates for various components of the total transport sector greenhouse contribution not fully covered by the values given in Table 5 (i.e. for direct CO_2 equivalent emissions from civil domestic energy use, see Chapter 5 of BITRE 2010 for more details).

Figure 15 shows ballpark estimates for the extension of the Base Case 2010 results (for FFC direct CO_2e) to incorporate rough allowances for:

- indirectly radiative effects, such as due to ozone-forming emissions of gases like carbon monoxide and nitrogen dioxide (with ozone being a powerful direct greenhouse gas) which can be considered as indirect greenhouse gases; and
- other directly radiative emissions due to transport vehicle use that either (like the indirect gases) are not currently allocated precise GWP values (such as the black carbon portion of vehicle particulate emissions) or are typically covered by other sectors within the NGGI (such as fugitive releases of fluorocarbons from refrigerated transport and motor vehicle air-conditioners).

As can be seen from the plotted trend in Figure 15, this results in estimated FFC levels for **total** CO_2 equivalent emissions (i.e. direct + indirect gases) from civil domestic transport averaging at least 20 per cent higher than from the **direct** CO_2 equivalent contribution alone (given by the lower 4 sections of the stacked area chart, and equal to the levels plotted in Figure 13).



Sources: BITRE (2010), BITRE estimates.

Figure 15: Base case projections for the full greenhouse contribution of Australian civil domestic transport, indicative long-term estimates.

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.

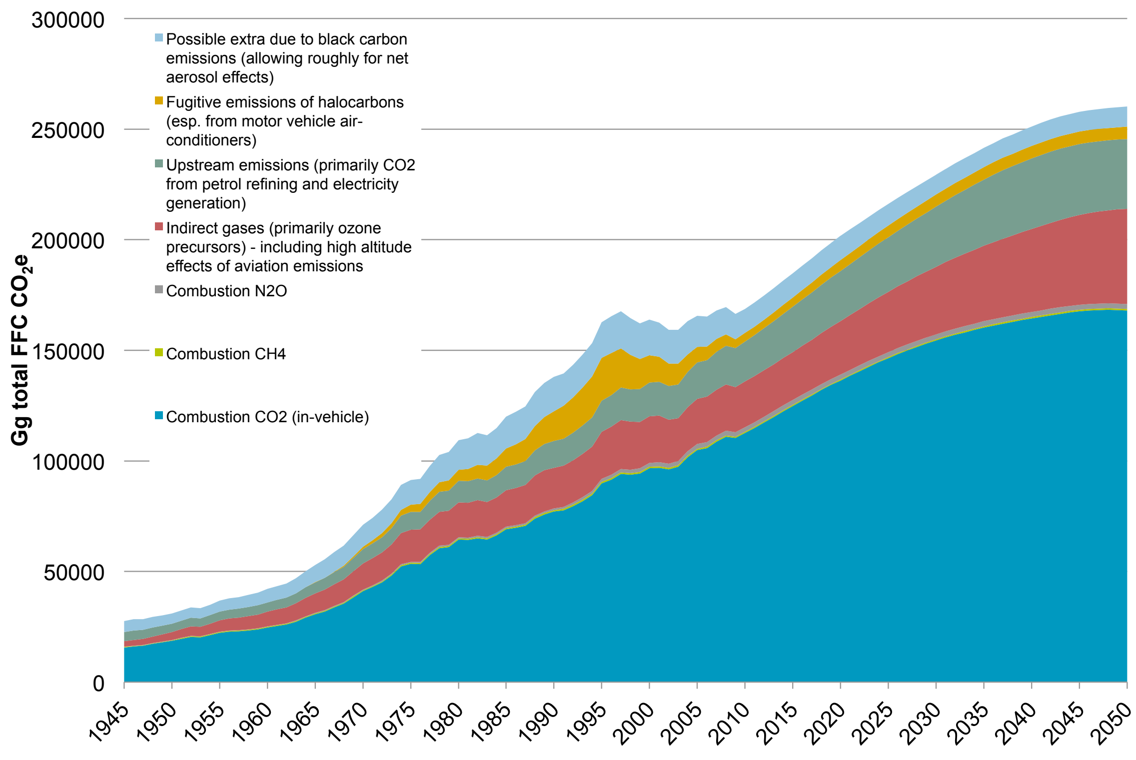
The fourth component of the graph allows for full fuel cycle (FFC) effects, by re-allocating fuel processing emissions (that are due to the supply of energy for transport vehicle use) from the *Energy Industries* section of the NGGI to the relevant transport end-uses. The primary emission sources for this section are due to electricity generation (for railways and battery-equipped vehicles), from petroleum refining, and from biofuel production.

Estimated emission volumes of the indirectly radiative gas species CO, NO_x and NMVOCs are also included in the NGGI, as well as estimated SOx 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 long-term Global Warming Potential (GWP) factors, and the NGGI does not yet assign CO_2 equivalent values to them. The fifth component here provides a rough estimate of their likely net radiative effects.

The sixth component of the graph is based on estimated halocarbon (CFC and HFC) releases from motor vehicle air-conditioners, 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 SO_x and particulate matter 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.

These more comprehensive totals would be increased even further if a proportion of the emissions due to international transport to and from Australia were also included in the estimation process. To give some indication of possible magnitudes, Figure 16 displays rough estimates for total CO_2 equivalent emissions from Australian civil domestic and international transport (using a provisional allocation of half the emissions due to total fuel use by international shipping and aviation travelling to and from Australia), also projected to 2050.



Sources: BITRE estimates, BITRE (2010).

Figure 16: Estimated FFC direct and indirect CO_2 equivalent emissions from Australian civil domestic and international transport.

Notes: The 'total' CO_2 equivalent values given are a 'central estimate' for the total warming effects of Australian civil transport (including both direct and indirect radiative effects, from the gaseous species CO_2, CH_4, N_2O, CO, NO_x and NMVOCs, and from aerosols (due to particulate and SO_x emissions from transport).

Emission totals for FFC values include upstream fuel supply and processing emissions (such as from power generation for electric railways and vehicles, or from petrol refining), as well as from end-use combustion, and also 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 also include emissions due to half the fuel used by international transport to and from Australia.

Such order-of-magnitude estimates for more complete transport sector contributions to the anthropogenic greenhouse effect are generally greater than double the standard *inventory accounting* totals for Australian transport (i.e. for domestic transport energy end-use, in direct CO_2 equivalent, as plotted in Figure 12).

The levels displayed in Figure 16 would be even higher still, if various other transport-related emissions were included, such as from:

- military vehicle fuel use
- energy use for commodity movements by pipelines
- additional life-cycle emissions, from sources associated with transport vehicle and infrastructure provision (e.g. emissions from energy used in vehicle construction, repairs and disposal; energy use for rail-track construction, maintenance and signal operation; energy consumption due to road lighting, traffic control, railway stations and airports)
- other fugitive losses, including evaporative emissions from service stations.

The ALCTF analyses use full fuel cycle evaluations to address a range of issues related to vehicle operation emissions not always adequately representing a full sectoral contribution. As well, some of the infrastructure options include analysis of extra life-cycle effects (with energy used to produce various road pavement materials being investigated). Yet for some other options examined, such as the future provision of new technology vehicles, further life-cycle considerations (such as the energy required to produce those new vehicles) could be significant. In the main, the ALCTF evaluations have ignored additional life-cycle effects (such as from vehicle manufacture) since they are typically dwarfed by the emissions due to vehicle activity (especially given increasing trends for materials recycling within the vehicle industry). For example, comparisons between results given in Figure 5.5 and Figure 5.6 of BITRE (2010) serve to demonstrate that the extra life-cycle emissions due to annual vehicle and infrastructure construction are not insignificant, but that vehicle operation typically accounts for at least 80-90 per cent of the full sectoral emissions due to transport provision.

ALCTF package of measures summary: aggregate scenario relative to the base case

In summary, a base (or reference) case projection to 2050 for the domestic transport sector and its modal sub-components was prepared, using BITRE (2010), as documented in the previous section.

A final list of 47 abatement options, assembled during the ALCTF Workshop process (also documented in a previous section) could then be assessed, in terms of potential emission reductions relative to that base case scenario. The options were assessed for the maximum level of abatement the Forum regarded as achievable by 2050 (i.e. technically feasible over the longer term, independent of explicit cost considerations, and though possibly approaching the limits of social and economic constraints, judged by the ALCTF Workshop participants as likely to be within those limits).

Having assembled the options, they were assessed using the simple framework demonstrated earlier (using an assumed 'adoption fraction' and an estimated emission 'savings fraction' operating on a projected 'market emissions' value). The options were assessed:

1. as if they were implemented 'in isolation' from the other options
2. as if they were implemented 'in sequence', as part of an aggregate package of strategies (the sequence, shown in Table 4, being agreed amongst the workshop participants as a logical evaluation order.

For the evaluation process, the options were grouped into seven major categories (see Table 4):

1. Vehicle and fuel technologies
2. Price signals
3. Regulation
4. Urban transport
5. Infrastructure
6. Freight
7. Other

The study initially calculated the individual impact of each option 'in isolation' (i.e. the abatement impact that the option would have if all else stayed the same). This approach allows us to see each option's potential without the operation of other options. The assessment of emission reduction potential 'in isolation' for the 47 options is shown in Figure 17 and Table 6 (providing values for *individual* abatement potential in terms of megatonnes of full fuel cycle direct CO_2 equivalent reduced per annum by 2050).

Note that the cumulative total column in Table 6 ends up with a reduction value of 220 Mt CO_2e across the full set of options – obviously not appropriate as an aggregate emissions abatement estimate, since the total base case emission projection for the 2050 transport sector is substantially less, at around 140 Mt CO_2e.

This motivates the more detailed aggregation investigation summarised in Figure 18 and Table 7 (providing values for the *in sequence* contribution to the aggregate abatement potential, again in terms of megatonnes of full fuel cycle direct CO_2 equivalent reduced per annum by 2050).

In Table 7, in an attempt at a more realistic *aggregate* reduction estimate, we have combined all of the abatement options sequentially for the 2050 'maximum abatement' case, introducing each option to the calculation in the order shown (as per Table 4), from top to bottom, allowing for overlapping abatement effects. In particular, note how the 'market emissions' amounts (for a specified market, such as use of light vehicles) decline as you move down that column (especially when compared to the respective values in Table 6), as each option's sequential abatement reduces the remaining emission totals for the options listed below. As discussed previously, the chosen ordering artificially inflates the relative contributions of those options that happen to appear higher in the listing – and to gain a more accurate indication of a particular option's comparative potential (especially for an option appearing towards the bottom of the ordering), one has to look instead at the 'individual' abatement values (such as provided in Table 6).

The total abatement achieved (in this 'maximum' case) by 2050 is about 108 Mt CO_2e for the aggregate scenario estimation, against reference case emissions in that year of about 140 Mt CO_2e (or a baseline of around 144 Mt CO_2e if also including certain emissions due to energy used while producing a range of road pavement materials).

Reducing the 2050 base case projection for Australian transport emissions by over three-quarters, this aggregate abatement estimate (displayed in Figure 19 by cumulating the option estimates), implies that there should be substantial scope for lowering BAU emissions from the domestic transport sector over the coming decades – as long as any social or investment cost obstacles, to the options' implementation, can be successfully overcome.

Extra (up-front) cost requirements and issues around social acceptability or required government intervention will vary widely between the various options – with some alternatives involving substantial extra investment costs, at least initially (such as high-technology motor vehicles); while others may be capable of already delivering abatement at net social benefits (such as urban congestion pricing – see Chapter 18 of BTCE 1996b). Though the ALCTF did not consider cost issues in detail, given the overall importance of such expenditure concerns to how likely actual implementation of certain options will be, a rough (order of magnitude) investment assessment of the Aggregate scenario's package was attempted.

Based on various literature values for relative abatement or required investment costs (such as provided in AECOM 2009, AECOM et al. 2011, BTCE 1996b, BTCE 1997, ClimateWorks 2011, McKinsey & Co 2009) it appears that the incremental investment (relative to the base case, primarily for extra vehicle technology) required to deliver the aggregate scenario's level of abatement could possibly involve costs of about $5-10 billion per annum. Over the first couple of decades, this would probably involve net social costs (possibly averaging, across the package of measures, in the order of $20 per tonne of CO_2 abated). However, as many of the novel technologies become more established over time, their incremental costs are likely to reduce – such that by the latter decades of the projection period, net abatement costs are expected to be negative (i.e. deliver net social benefits, with the up-front incremental investment costs more than balanced by advantages such as reduced fuel consumption, traffic congestion improvements or health benefits from better urban air quality).

Indicative estimates of the possible net social costs over the full projection period imply that the considerable investment costs likely to be required for the aggregate scenario's implementation could be roughly balanced (by 2050) by those social benefit elements (primarily aggregate fuel cost savings).

If the aggregate scenario's full abatement were to be achieved, a possible time-path to 2050 (based on the Workshops' views on short-term versus longer-term implementation feasibility/capability) is given in Figure 20 (compared with the timeline for the base case projections), and the modal composition of this interpolated emission reduction path is displayed in Figure 21.

The aggregation process conducted here is approximate. That is, it only roughly considers how various separate options will interact when they are jointly or concurrently implemented – and a full analysis of all the possible synergies or discords between different options is beyond the scope of this present study. However, the method detailed here yields a straightforward manner of estimating a rough (order of magnitude) value for how such a full package of transport measures could combine, to obtain an aggregate value for the long-term level of abatement possible across the transport sector.

The main results of the analysis are summarised in the following tables and figures.

Table 6: Individual option assessment

Individual option abatements Mode/Category	Option	Light road vehicles	Road freight	Domestic aviation	Domestic maritime	Rail	Bus	Infra-structure	'Individual' abatement Cumulative total (2050 Mt CO_2e)	Assumed adoption fraction	Modal sub-sector or market affected	'Individual' market emissions (2050 Mt CO_2e)	Estimated savings fraction
		(Abatement in 2050, Mt FFC direct CO_2 equivalent)											
1. VEHICLE and FUEL TECHNOLOGY													
Light vehicles	electric/plug-in cars	35.8							35.83	0.61	light vehicles	72.9	0.8
	fuel super-efficiency	27.3							63.08	1.00	light vehicles	68.1	0.40
	downsizing	18.2							81.30	1.00	light vehicles	72.9	0.25
	bio-fuels	29.4							110.66	0.62	light vehicles	72.9	0.65
Trucks	engine efficiency		5.4						116.08	1.00	Trucks	36.1	0.15
	low rolling resistance		0.4						116.44	0.10	Trucks	36.1	0.1
	regenerative braking		1.6						118.08	0.90	Urban rigids	9.1	0.2
	electric trucks		2.0						120.12	0.30	Urban rigids	9.1	0.75
	biodiesel		16.4						136.56	0.70	Trucks	36.1	0.65
Aviation	technology			5.2					141.78	1.00	domestic aviation	17.4	0.3
	bio-fuels			7.8					149.60	0.75	domestic aviation	17.4	0.6
Maritime	technology				0.7				150.29	1.00	domestic shipping	2.3	0.3
	bio-fuels				2.41				152.70	0.85	all water craft	4.4	0.65
Rail	technology					0.9			153.64	1.00	all rail	6.3	0.15
	bio-fuels					3.0			156.61	0.85	non-electric rail	5.4	0.65
Bus	technology						0.5		157.14	1.00	buses	2.7	0.2
	electric buses						0.5		157.66	0.35	urban buses	1.9	0.8
	bio-fuels						1.4		159.01	0.82	buses	2.5	0.65
2. PRICE SIGNALS													
Variable price	road/congestion pricing	7.0							166.05	0.70	Urban light vehs	43.7	0.23
			0.9						166.91	0.60	Urban trucks	14.3	0.1
Pay-As-You-Drive	distance based charges	5.5							172.37	1.00	All light vehs	72.9	0.075
	(Rego, insurance etc)		1.1						173.46	1.00	Trucks	36.1	0.03
Commuter	parking charges	0.4							173.89	1.00	Urban light vehs	43.7	0.01
3. REGULATION													
Light Vehicles	moderate L/100km standards	7.3							181.18	1.00	light vehicles	72.9	0.1
Trucks	B-triples		0.6						181.80	0.55	B-doubles	11.3	0.1
	PBS trucks		0.8						182.60	0.22	Trucks	36.1	0.1
All vehicles	gross polluter control	0.84	0.6						184.00	0.90	non-elec vehicles	104.3	0.015
4. URBAN TRANSPORT													
Urban vehicle demand	urban form/design	3.48	0.9						188.35	0.50	Urban vehs	58.0	0.15
Rail/bus	telecommuting					0.02	0.02		188.38	0.05	Urban public transport	2.5	0.25
Light vehicles	TDM, inc telecommuting	1.31							189.70	0.10	Urban light vehs	43.7	0.3
	mode shift car-UPT	3.9							193.59	0.15	Urban light vehs	43.7	0.59
	mode shift car-walk	0.24							193.83	0.30	Urban LV trips < 2km	0.8	1.00
	mode shift car-cycle	1.44							195.27	0.20	Urban LV trips < 10km	7.2	1.00
	mode shift car-velomobile	1.31							196.58	0.10	Urban LV trips < 20km	13.8	0.95
	eco-driving	2.5							199.03	0.45	light vehicles	68.1	0.08
5. INFRASTRUCTURE													
Hard	pavement design							0.18	199.21	0.20	road construction	3	0.3
	pavement smoothing	1.75	0.87				0.06		201.89	0.80	All vehicles	111.7	0.03
	pavement materials							0.11	202.00	1.00	road resurfacing	1	0.11
Soft	airspace management			1.7					203.74	1.00	domestic aviation	17.4	0.1
	traffic management	2.19	0.71				0.09		206.73	0.50	All urban vehicles	59.9	0.1
	UPT priority + info					0.06	0.06		206.86	0.50	UPT	2.5	0.1
6. FREIGHT													
All freight	mode shift road-rail		4.0						210.86	0.40	intercapital trucking	14.7	0.68
	mode shift road/rail-sea		1.1						211.98	0.12	IS rail / trucks	11.9	0.76
	improved logistics		4.5			0.2			216.65	0.50	IS rail / trucks	37.3	0.25
Heavy vehicles	eco-driving		0.9				0.07		217.62	0.50	heavy vehicles	38.80	0.05
7. OTHER													
Aviation	telecommuting			0.9					218.48	0.20	domestic aviation	17.4	0.25
Rail	High Speed Rail			1.7					220.20	0.14	domestic aviation	17.4	0.71
											total transport - base case	140	
Total 2050 abatement (all measures, inc infrastructure)		149.8	42.8	17.4	3.1	4.1	2.7	0.3	220.20		inc pavement materials	144	

Table 7: Aggregate, in sequence, assessment

In sequence aggregate abatement Mode/Category	Option	Light road vehicles	Road freight	Domestic aviation	Domestic maritime	Rail	Bus	Infra-structure	'In sequence' abatement Cumulative total (2050 Mt CO_2e)	Assumed adoption fraction	Modal sub-sector or market affected	'In sequence' market emissions (2050 Mt CO_2e)	Estimated savings fraction
		(Abatement in 2050, Mt FFC direct CO_2 equivalent)											
1. VEHICLE and FUEL TECHNOLOGY													
Light vehicles	electric/plug-in cars	22.8							22.80	0.39	light vehicles	72.9	0.8
	fuel super-efficiency	14.3							37.11	1.00	light vehicles	40.1	0.36
	downsizing	5.1							42.26	1.00	light vehicles	35.7	0.14
	bio-fuels	11.8							54.01	0.82	light vehicles	22.1	0.65
Trucks	engine efficiency		5.4						59.43	1.00	Trucks	36.1	0.15
	low rolling resistance		0.3						59.74	0.10	Trucks	30.7	0.1
	regenerative braking		1.0						60.77	0.90	Urban rigids	7.6	0.15
	electric trucks		1.5						62.26	0.30	Urban rigids	6.6	0.75
	biodiesel		13.6						75.86	0.75	Trucks	27.9	0.65
Aviation	technology			5.2					81.07	1.00	domestic aviation	17.4	0.3
	bio-fuels			6.2					87.28	0.85	domestic aviation	12.2	0.6
Maritime	technology				0.7				87.97	1.00	domestic shipping	2.3	0.3
	bio-fuels				2.03				90.00	0.85	all water craft	3.7	0.65
Rail	technology					0.9			90.94	1.00	all rail	6.3	0.15
	bio-fuels					2.4			93.39	0.85	non-electric rail	4.4	0.65
Bus	technology						0.5		93.92	1.00	buses	2.7	0.2
	electric buses						0.4		94.33	0.35	urban buses	1.5	0.8
	bio-fuels						0.7		95.07	0.82	buses	1.4	0.65
2. PRICE SIGNALS													
Variable price	road/congestion pricing	1.8							96.89	0.70	Urban light vehs	11.3	0.23
			0.3						97.18	0.60	Urban trucks	4.9	0.1
Pay-As-You-Drive	distance based charges	1.3							98.46	1.00	All light vehs	17.0	0.075
	(Rego, insurance etc)		0.4						98.88	1.00	Trucks	14.0	0.03
Commuter	parking charges	0.1							98.97	1.00	Urban light vehs	8.7	0.01
3. REGULATION													
Light Vehicles	moderate L/100km standards	0.0							98.97	1.00	light vehicles	0.0	0.1
Trucks	B-triples		0.2						99.20	0.55	B-doubles	4.2	0.1
	PBS trucks		0.3						99.50	0.22	Trucks	13.3	0.1
All vehicles	gross polluter control	0.16	0.1						99.77	0.90	non-elec vehicles	20.4	0.015
4. URBAN TRANSPORT													
Urban vehicle demand	urban form/design	0.80	0.2						100.76	0.50	Urban vehs	13.3	0.15
Rail/bus	telecommuting					0.01	0.01		100.78	0.05	Urban public transport	1.1	0.25
Light vehicles	TDM, inc telecommuting	0.2							101.01	0.10	Urban light vehs	7.8	0.3
	mode shift car-UPT	0.53							101.54	0.15	Urban light vehs	7.6	0.46
	mode shift car-walk	0.12							101.66	0.40	Urban LV trips < 2km	0.3	1.00
	mode shift car-cycle	0.33							101.99	0.25	Urban LV trips < 10km	1.3	1.00
	mode shift car-velomobile	0.30							102.29	0.15	Urban LV trips < 20km	2.1	0.95
	eco-driving	0.2							102.52	0.45	light vehicles	12.7	0.04
5. INFRASTRUCTURE													
Hard	pavement design							0.15	102.67	0.20	road construction	2.5	0.3
	pavement smoothing	0.30	0.31				0.03		103.30	0.80	All vehicles	26.5	0.03
	pavement materials							0.08	103.38	1.00	road resurfacing	0.7	0.11
Soft	airspace management			0.6					103.98	1.00	domestic aviation	6.0	0.1
	traffic management	0.28	0.22				0.04		104.51	0.50	All urban vehicles	10.6	0.1
	UPT priority + info					0.04	0.04		104.58	0.50	UPT	1.4	0.1
6. FREIGHT													
all freight	mode shift road-rail		1.20						105.78	0.40	intercapital trucking	5.1	0.58
	mode shift road/rail-sea		0.40						106.18	0.11	IS rail / trucks	4.5	0.79
	improved logistics		1.3			0.2			107.69	0.50	IS rail / trucks	12.0	0.25
Heavy vehicles	eco-driving		0.18				0.02		107.89	0.50	heavy vehicles	10.28	0.04
7. OTHER													
Aviation	telecommuting			0.3					108.15	0.20	domestic aviation	5.4	0.25
Rail	High Speed Rail			0.1					108.28	0.15	domestic aviation	5.1	0.17
											total transport - base case	140	
Total 2050 abatement (all measures, inc infrastructure)		60.48	27.03	12.42	2.72	3.61	1.81	0.23	108.28		inc pavement materials	144	

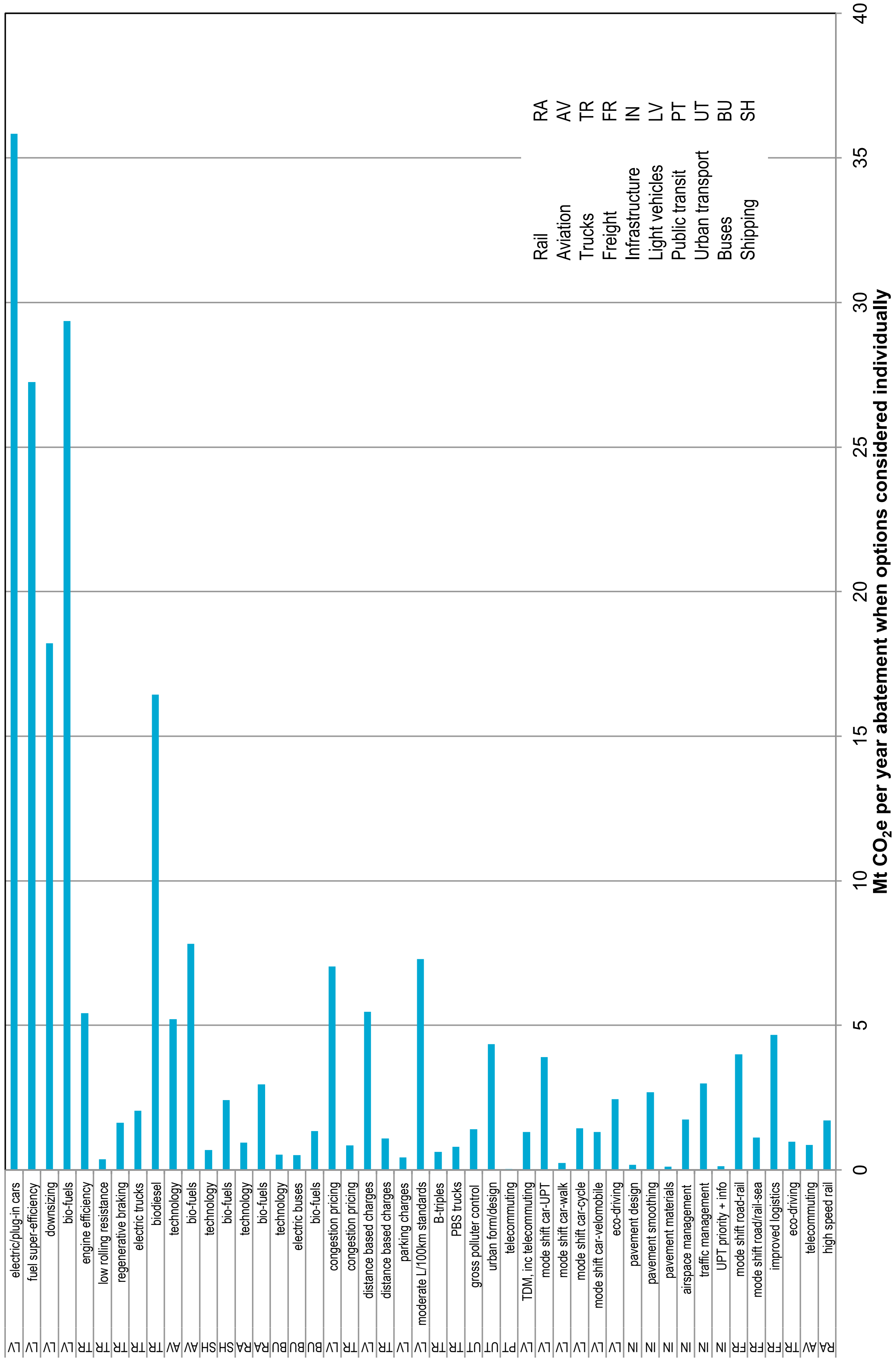


Figure 17: Individual abatement potential, megatonnes CO_2 equivalent per annum by 2050.

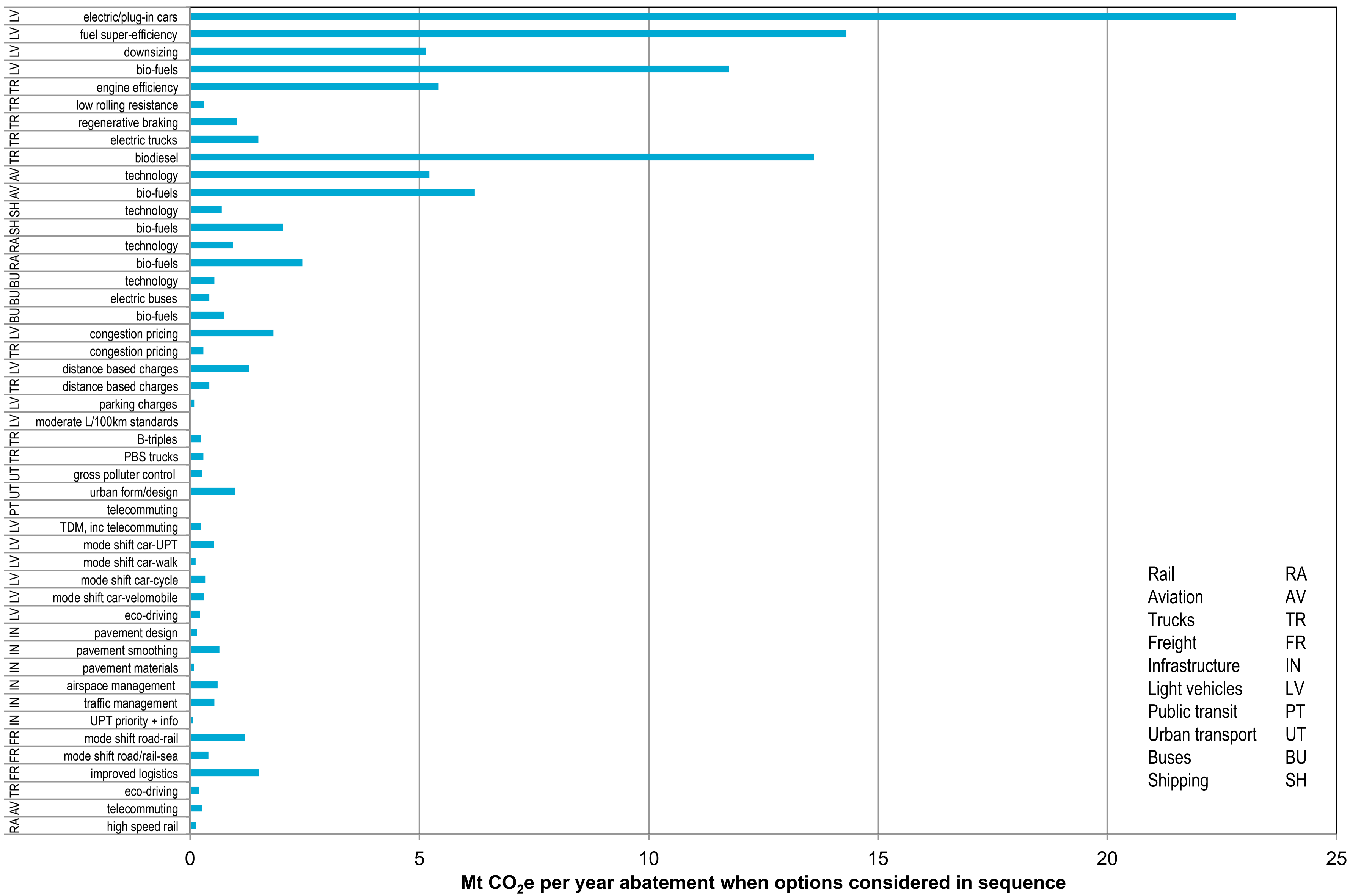


Figure 18: Sequential abatement contribution to aggregate potential, megatonnes CO_2 equivalent per annum by 2050.

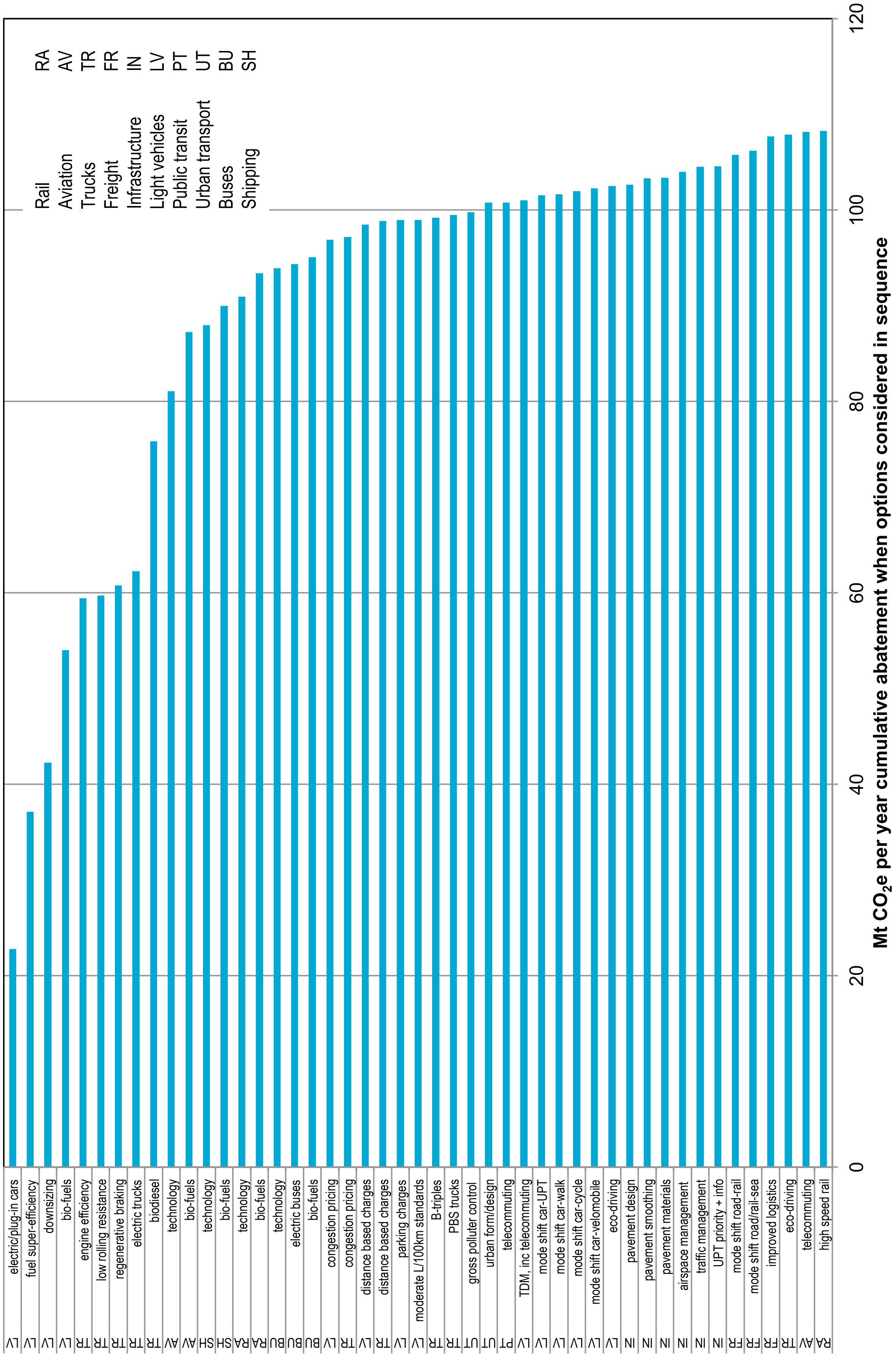
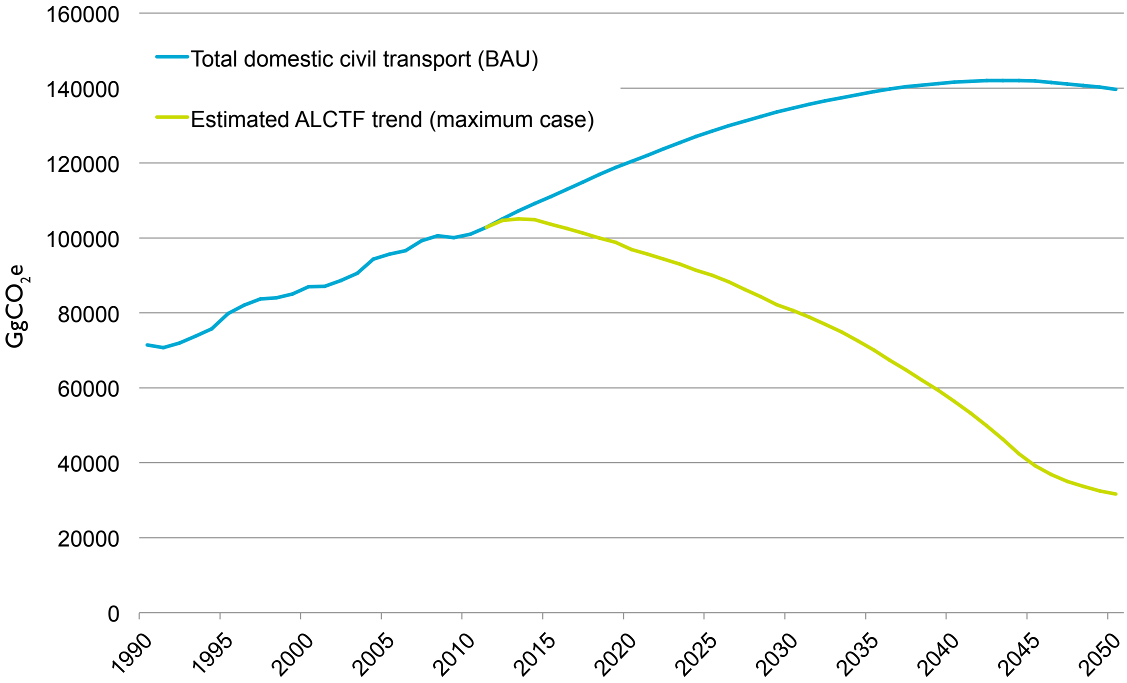


Figure 19: Cumulative abatement, options considered in sequence, megatonnes CO_2 equivalent per annum by 2050.



Sources: BITRE estimates, BITRE (2010).

Figure 20: Aggregate ALCTF scenario emissions, relative to the reference case trend, gigagrams CO_2 equivalent.

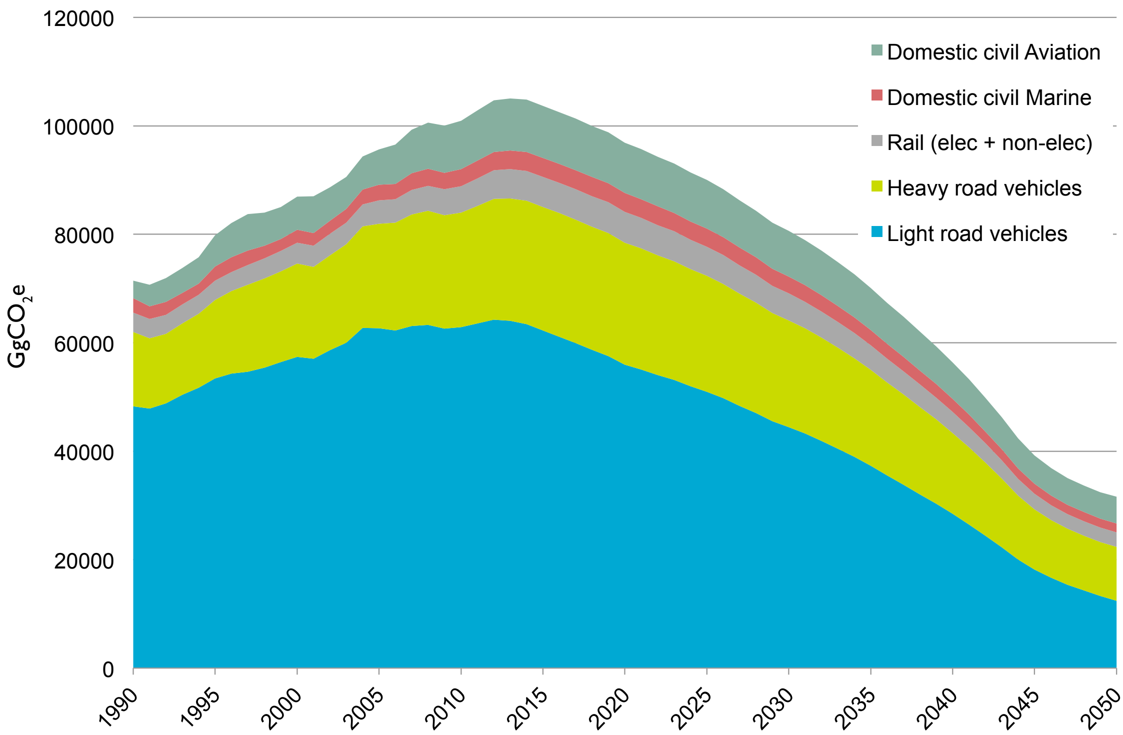


Figure 21: Aggregate ALCTF scenario emissions, by mode, gigagrams CO_2 equivalent.

Option outlines by abatement category

1. VEHICLE AND FUEL TECHNOLOGY

Of the seven categories that the aggregate scenario has been subdivided into, 'Vehicle and fuel technology' offers the largest abatement potential (but also has some of the largest uncertainties around the exact likelihood of eventually obtaining that estimated emission reduction capability – such as unknowns concerning the amounts of biofuel that are likely to be produced sustainably, and how rapid future take-up will be of new technology such as plug-in hybrid vehicles).

For each option in Table 4, the separate lines from Tables 6 and 7 (for their respective estimates of *individual* abatement potential and *in sequence contribution* to the aggregate potential) are collated and described in the following sections, where some background details are provided for all of the option assessments.

Electric cars and light vehicle fuel intensity reduction

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Electric/plug-in cars	0.61	Light vehicles	72.9	0.80	35.8
Vehicle technology	Fuel super-efficiency	1.00	Light vehicles	68.1	0.40	27.3
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Electric/plug-in cars	0.39	Light vehicles	72.9	0.80	22.8
Vehicle technology	Fuel super-efficiency	1.00	Light vehicles	40.1	0.36	14.3

The first level of implementation in the ALCTF Aggregate Scenario (for maximum emission reductions from the Australian domestic transport sector by 2050) uses the joint results of two individual options originally assessed for Workshop 2 – 'Radical fuel intensity reductions for light passenger vehicles' and 'Electric light vehicles'. These options have some of the largest potentials assessed by the ALCTF process, both for individual abatement, and as part of the first main category (Vehicle and fuel technology) that the various options have been divided into for the aggregation process.

Estimates of the emission savings capable of being gained from changes to light vehicle design can be based on assessments of the potential fuel consumption advantages of technological innovations – such as the King Review *(The King Review of Low-Carbon Cars, Part 1: the Potential for CO_2 Reduction,* King 2007); *Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035* (Cheah 2008); *Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015* (DeCicco, An and Ross 2001); *The technology pathway to clean and efficient road transport* (Friedrich 2008); *Assessment of Technologies for Improving Light Duty Vehicle Fuel Economy* (Jones 2008) – and reports on planned standards for future new car fleets, particularly in Europe *(Progress report on implementation of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles,* Interim Joint Technical Assessment Report, European Commission 2010) and the US *(Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025,* U.S. Environmental Protection Agency 2010).

Using such considerations, a BITRE ATRF paper ('The Spread of Technologies through the Vehicle Fleet', Gargett, Cregan and Cosgrove 2011) presents a scenario for the Australian light vehicle fleet that assumes radical fuel intensity reductions are feasible over the coming decades (essentially requiring technologies such as hybridisation drastically increasing their fleet penetration). Based on this fleet scenario, which has electric and plug-in hybrid vehicles each reaching eventual (new car) market shares of about a quarter each, and where the rated fuel intensity of new (non-electric) light vehicles falls to about 3-4 L/100 km between 2030 and 2050 – compared to a baseline projection of gasoline (non-battery) cars reaching around 6.5 L/100 km by 2050 – a potential emission saving fraction (fleet-wide) of about 0.46 (by 2050) was derived (using the BITRE vehicle fleet models).

For the overall abatement evaluation (presented in Table 7), many of the individual options are introduced to the aggregation process one by one – though in some cases (as for these first two options), several are brought in together (e.g. where it has been assessed that various industry/market modifications are more likely to occur in concert than totally independently). For this initial part of the Aggregate Scenario, it has been assumed that the light vehicle fleet undergoes a radical de-carbonisation, utilising a range of technical opportunities – shared between electrification options and other technologies improving liquid fuel efficiencies.

Specifically, for the aggregation scenario, it has been assumed that approximately half of annual light vehicle fleet kilometres are performed by electric propulsion by 2050 (i.e. either in dedicated electric vehicles or in plug-in hybrid vehicles using both electricity and liquid fuels) – up from a level of approximately 15 per cent of VKT in the base case projection scenario. This first component of the joint technology changes to the light vehicle fleet (under the aggregation sequence) has been estimated as capable of about 23 million tonnes (full fuel cycle direct CO_2 equivalent) of abatement annually by 2050 – off a base-case emission projection for Australian light vehicles of around 73 Mt (2050 FFC direct CO_2 equivalent).

If pursued individually (i.e. in the absence of a range of other measures dedicated to reducing vehicle emissions, so not having to share new vehicle sales with competing energy efficiency technologies), this part of the joint technology option (i.e. light vehicle electrification) could probably have its estimated maximum adoption fraction increased – where the 'individual' abatement value given in the upper-most row of the assessment table has been derived with an assumed fleet VKT fraction of 0.7, resulting in an estimated level of almost 36 Mt annually (by 2050) for electrification's stand-alone abatement potential.

One of the crucial assumptions underpinning such a result is the generation source for electric power – where, as detailed previously, the ALCTF estimates are based on Treasury's 'core policy' scenario for electricity generation (see Treasury 2011 modelling, http://www.treasury.gov.au/carbonpricemodelling/content/default.asp; Figure 5.18 of Commonwealth of Australia 2011a).

The calculated emission savings would be substantially reduced if 2050 electricity generation was still primarily due to standard coal-fired power stations, since this Treasury scenario assumes that the supply of electricity de-carbonises strongly in the future, essentially under the effects of the Government's Clean Energy Act. The decarbonisation rate assumed in the Treasury 'core policy scenario' (from Strong Growth, Low Pollution, Commonwealth of Australia 2011a) is summarised in the following table.

Table 8: Forecast electricity generation emissions
(tonnes of CO_2 equivalent per megawatt-hour delivered)

Reference		Core policy	
2020	2050	2020	2050
0.771	0.73	0.724	0.209

Sources: Treasury modelling, Commonwealth of Australia (2011a).

The next step of the aggregation process then assumes the remaining (non-battery-equipped) light vehicles have their average fuel intensities gradually reduced (as new cars move into the vehicle fleet) – with technology improvements along the lines investigated in studies such as the King Review. Further use of fuels with a lower carbon content than standard petroleum, such as natural gas and LPG also offer some emission intensity improvements for portions of the light vehicle fleet.

The 'in-sequence' contribution to aggregate abatement for this second part of the joint 'light vehicle technology' step (after allowing for the base or reference case improvements in fuel efficiency) has been estimated at about 14 Mt annually by 2050 (lower-most row of the assessment table – where the estimated 'savings fraction' here relates to a value for the entire light vehicle fleet, allowing for the gradual diffusion of the presumed technical innovations into the fleet, as new vehicle sales enter and older vehicles are scrapped, evaluated using the BITRE vehicle fleet models).

The estimated 'individual' option abatement (i.e. potential abatement from engine improvements in the absence of vehicular electrification) has been calculated at about 27 Mt (higher not only because of the larger 'market emissions' – i.e. base case levels for non-electric vehicle use, rather than the residual market of the lower-most table row – but also with the 'savings fraction' being set to a slightly higher value, due to reduced overlap, when considered in isolation, with electrification options).

The aggregation of these light vehicle technology options results in about 37 Mt for 2050 abatement (relative to the base case). Due to the substantial lags in such fleet technology options, where the introduced technologies have to gradually diffuse throughout the vehicle fleet over time, as older (less energy-efficient) vehicles are scrapped and replaced, the abatement potential estimated for the short to medium terms is substantially lower than these longer term results.

Note that this joint technology option assumes that a range of straightforward or low-cost measures capable of improving energy efficiency in light vehicles – such as encouraging the greater penetration of low resistance tyres – are pursued as part of the package.

For example, the literature typically finds that about a 5 to 10 per cent reduction should be feasible in average light vehicle rolling resistance through fitting low resistance tyres. Fleet-wide estimates of potential fuel savings vary between about 1 to 5 per cent – e.g. *California State Fuel-efficient Tire Report: Volume I,* California Energy Commission 2003, http://www.energy.ca.gov/reports/2003-01-31_600-03-001F-VOL1.PDF; *Tires and passenger vehicle fuel economy: Informing consumers, improving performance*, Transportation Research Board 2006, http://onlinepubs.trb.org/onlinepubs/sr/sr286.pdf; *Progress report on implementation of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles*, Interim Joint Technical Assessment Report, European Commission 2010.

Car downsizing

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Downsizing	1.00	Light vehicles	72.9	0.25	18.2
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Downsizing	1.00	Light vehicles	35.7	0.14	5.1

Standard statistics on new Australian passenger vehicles typically categorise car sales into 'small', 'medium', 'large' and 'SUV' (sports utility vehicle) components. For the downsizing option assessed in the ALCTF workshops, it has been assumed a 'micro' car class gradually gains a much more significant market share over time – comprising vehicles, on average, substantially smaller than most current 'small' vehicles, but still having the general configuration of a standard sedan, i.e. ranging in size from current 'city cars' and subcompacts down to very small vehicles along the lines of the previous TG500 sports car (http://en.wikipedia.org/wiki/Messerschmitt_TG500) and BMW Isetta (http://en.wikipedia.org/wiki/Isetta); but not necessarily envisaging possible large-scale take-up of ultra-light vehicles (like the Corbin_Sparrow, http://en.wikipedia.org/wiki/Corbin_Sparrow) that can be more akin to motorcycles or powered-assisted cycles (and will not always satisfy current automobile licensing/registration classifications).

For the scenario evaluation it was assumed that this micro car class would have an average fuel consumption of about 2 L/100 km, and eventually reach a level where about half of the 'small' car share in the base case projections gets displaced by 'micro' sales. Overall, 'small' car sales in this particular scenario do not fall greatly from the baseline level, even with this substantial amount of car-buyers moving to even smaller vehicles, since it was furthermore assumed that about a third of baseline medium, large and SUV sales also downsize (primarily to the 'small' category).

When input to the BITRE vehicle fleet models, this presumed compositional mix for a downsized car fleet gave estimated fuel savings of at least 20 per cent (relative to the base case) – and if the micros were to be largely electric (again under Treasury's 'core policy' scenario for the power generation mix, with the emission intensity of electricity generation decreasing over time) then emission reductions approaching 30 per cent should be feasible by 2050.

The 'individual' abatement potential presented in the assessment table (top row) assumes a savings fraction of 0.25, roughly mid-way between these alternative values – giving an estimate for 2050 maximum abatement of about 18 Mt CO_2e per annum (though with the *likely* adoption of such an option being highly uncertain, and heavily dependent on how many Australian drivers can be persuaded to reduce the size of their future vehicle purchases).

For the 'in sequence' values in the assessment table (bottom row), the estimated emission reduction contributions are not as large (at about 5 Mt CO_2e per annum by 2050):

- partly due to the previous part of the package aggregation (i.e. greater use of electric cars and radical fuel intensity reductions) already improving the emissions intensity of each kilometre of light vehicle travel by this step in the aggregate scenario (accounted for in a reduction of the 'market emissions' in the table, from the base case result for 2050 light vehicle use of about 73 Mt, down to about 36 Mt for the residual market value)
- partly since it is assumed that there are some overlapping elements with average vehicle down-sizing and the previous electrification and high fuel-efficiency option (especially concerning vehicle weight reductions to improve fuel consumption), leading to a decrease in the estimated savings fraction from the potential assumed in the 'individual' option assessment.

Though the likely abatement is estimated to be significant under this car downsizing scenario, even greater savings are possible if even smaller vehicles (e.g. power-assisted bicycles and tricycles, velomobiles and other ultra-light vehicles) eventually gain significant passenger share (assuming any concerns around on-road safety can be successfully addressed). The available range of single-seat, ultra-small vehicles has started to widen in recent times – including Personal Electric Vehicles (PEVs, such as the 3-wheel vehicles produced by Myers Motors, http://en.wikipedia.org/wiki/Myers_Motors) – the use of which should have the theoretical capability of radically reducing urban vehicle emissions – if community acceptance of such very small vehicles were ever to reach significant proportions. (Note that abatement estimates for the possible switching of some urban car travel to power-assisted cycling are dealt with in a later section of the report.)

Biofuels for light vehicles

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Fuel technology	Bio-fuels	0.62	Light vehicles	72.9	0.65	29.4
'In sequence' calculated contribution to aggregate abatement						
Fuel technology	Bio-fuels	0.82	Light vehicles	22.1	0.65	11.8

This next part of the options aggregation package assumes most of the non-electric light vehicles run on biofuels/biofuel blends by 2050. For this particular scenario the major share of this use is assumed to be due to bio-derived ethanol (with an assumed biodiesel market share of about 10 per cent), from a range of currently available sources (1st generation biofuels) and projected future feedstock materials (2nd generation biofuels). Note that this option has one of the greater uncertainty levels associated with its abatement evaluations, since there is considerable on-going debate concerning issues such as: possible land use conflicts with food production; exactly how much biofuel volume can be produced sustainably; and how efficient various prototype biofuel production technologies will actually be when operating at large scale.

Depending on the feedstock, estimated likely abatement potentials for biofuels cover a wide range, typically spanning savings fractions of about 0.3 to 0.9, e.g. from grain-based to lignocellulose-derived ethanol, where a mid-range abatement fraction of 0.65 has been chosen for this scenario, roughly representative of emission factors for ethanol based on the use of crop stubble as a feedstock, after adding up all upstream emissions from the fuel production/lifecycle, with emission factors provided in studies such as:

- Farine, D. R. et al. (2011), An assessment of biomass for bioelectricity and biofuel, and greenhouse gas emission reduction in Australia, *Global Change Biology Bioenergy* (CSIRO journal article).
- Stratton, R.W., Wong, H.M. and Hileman, J.I. (2010), Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels: PARTNER Project 28, report Version 1.1, Report No. PARTNER-COE-2010-001, Partnership for Air Transportation, Noise and Emissions Reduction.

Considered 'in sequence', this step in the options aggregation is estimated to contribute about 12 Mt (FFC direct CO_2 equivalent) to 2050 total abatement (where the base case already incorporates a projected biofuel market share of about 8 per cent for light vehicles, and the ALCTF scenario envisages expanding this to 90 per cent, resulting in a net adoption fraction of about 0.82).

When considered as a stand-alone or individual option, the maximal abatement potential (i.e. assuming all available biofuel feedstocks are directed towards light vehicle use) has been estimated at close to 30 Mt per annum (FFC direct CO_2 equivalent) by 2050, assuming that supply constraints do not limit Australian ethanol and biodiesel use by the road transport sector to volumes below this level of implied consumption.

Based on CSIRO assessments of likely future availability of domestic biofuels (i.e. estimates in Farine et al. 2011 on the future volumes of biofuel that can potentially be supplied annually by sustainable domestic production), the scenarios place some limits on total biofuel use – where it is assumed that annual abatement greater than about 15-20 Mt CO_2e per annum for biodiesel and about 30-35 Mt CO_2e per annum for ethanol would probably suffer biofuel supply constraints, allowing for likely sustainable Australian feedstock availability and significant extra volumes from imports (of between 50-100 per cent of the size of the domestic availability).

For example, if the residual market for the 'in sequence' calculation had not already been so reduced by the options higher in the aggregation list (i.e. with the further electrification, downsizing and engine efficiency options taking the light vehicle 'market emissions' from its 2050 base case value of 72.9 Mt down to 22.1 Mt CO_2e), then the assumed expansion of the biofuel market could not have been set here to so high a level (90 per cent share) without breaching these assumed supply constraints – especially since, in the ALCTF Aggregate Scenario, the constraint applies to the summed biofuel consumption across all modes and vehicle types. For the 'individual' calculation, the size of the 2050 market emissions means that any higher market penetration than the assumed expansion level (i.e. to 70 per cent market share, for a net adoption fraction, relative to the base case trends, of about 0.62) would start to exceed likely ethanol availability, as imposed by the estimated biofuel supply limits.

Truck engine efficiency

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh/Fuel technology	Engine efficency	1.00	Trucks	36.1	0.15	5.4
'In sequence' calculated contribution to aggregate abatement						
Veh/Fuel technology	Engine efficency	1.00	Trucks	36.1	0.15	5.4

Improvements in the thermal efficiency of truck engines have a realistic potential to offer substantial emissions reduction in the medium to long term. Current truck engine thermal efficiency is typically assessed to be about 42-43 per cent, and new measures expected to be available by about 2018 offer further thermal efficiency improvements of up to 30 per cent (e.g. see *FY 2010 Progress Report for Advanced Combustion Engine Research and Development*, Energy Efficiency and Renewable Energy Vehicle Technologies Program, US DoE 2010, http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/2010_adv_combustion_engine.pdf). According to this source (DoE 2010, pg. 6), even though further improvements beyond a thermal efficiency of approximately 55 per cent are likely to be limited:

> 'Heavy-duty vehicles using diesel engines have significant potential to employ advanced combustion regimes and a wide range of waste heat recovery technologies that will improve engine efficiency and reduce fuel consumption.'

The DoE (2010) report also notes that suitable control of emissions of nitrogen oxides (NO_x) and particulate matter (PM) could remain a significant challenge for advanced diesel combustion strategies, and that

> 'numerous technologies are being investigated to reduce vehicle NOx emissions while minimizing the fuel penalty associated with operating these devices'.

Should further research and development make such technology (for improving engine efficiency) available, adoption is considered likely to be quite rapid. Truck manufacturers will be keen to implement cost-effective new engine efficiency technology as soon as it is available, in order to gain or maintain a competitive position (where this has often historically been the case). Given truck turnover rates, fleet adoption over the short term is likely to be limited (although there will be incremental change over the years), and even over the longer term it is possible that some efficiency measures may not be cost-effective and may not achieve full adoption (although this is becoming less likely with fuel price escalation).

Further use of natural gas (e.g. currently being used in CNG urban buses and as LNG for some line-haul trucks) also offers some emission intensity gains for the heavy vehicle fleet.

For this next step in the aggregate package of options, the 2050 abatement contribution has been estimated at around 5.4 Mt CO_2e per annum (after allowing for the likely truck fuel efficiency improvements already included in the base case scenario). Since this is the first addition to the aggregation package involving truck emissions (and this 'savings fraction' estimate has been assumed to be largely independent of other options), the 'individual' abatement estimate has been left at the same level (results roughly consistent with discussions concerning potential truck engine efficiency during the ALCTF Workshops).

Truck rolling resistance

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Low rolling resistance	0.10	Trucks	36.1	0.10	0.4
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Low rolling resistance	0.10	Trucks	30.7	0.10	0.3

Lowering the rolling resistance of truck tyres, and operating tyres at correct inflation pressures are two straight-forward methods of improving fuel efficiency, and thus reducing emissions. This assessment is based on the complete uptake of the existing technology to achieve lower rolling resistance, including operating tyres at recommended inflation pressures.

Tyre manufacturers (e.g. http://www.goodyear.com/truck/pdf/radialretserv/Retread_S9_V.pdf) typically indicate that the use of low rolling resistance tyres can reduce fuel consumption by 3-4 per cent, and that increasing the tyre pressures of underinflated tyres (e.g. from 70 psi to 100 psi) can reduce fuel consumption by the order of 5 per cent.

Abatement potential is estimated to be fairly limited, since an adoption level of 90 per cent for such measures is already included in the base case – leading to a net 'adoption fraction' of only 0.1 even with full fleet take-up of this option. The estimated 2050 abatement for this next step in the aggregate package sequence is estimated at about 0.3 Mt per annum (with about 0.4 Mt per annum for the individual potential).

Further improvements in truck rolling resistance (than the 0.1 savings fraction assumed here) could be achievable through new technologies presently under development. Klunder et al. (2009, *Impact of Information and Communication Technologies on Energy Efficiency in Road Transport)* consider the fitting of tyre pressure indicators to heavy vehicles as an effective means of reducing their average CO_2 emissions.

Truck regenerative braking

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Regenerative braking	0.90	Urban rigids	9.1	0.20	1.6
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Regenerative braking	0.90	Urban rigids	7.6	0.15	1.0

A regenerative brake is an energy recovery device which slows a vehicle by converting its kinetic energy into another form, which can be either used immediately or stored until needed. Energy is therefore accumulated during braking, and is returned to the vehicle when accelerating. While the potential of regenerative braking has been recognized for a long time, the practical implementation has been difficult, and as a result the market uptake has been slow. New technology such as 'Permodrive' (http://www.permodrive.com/benefit/index.htm) has demonstrated practical applications, and yielded fuel savings of approximately 20 per cent.

Initial uptake of this technology is expected to be slow. The significant capital investment required may hinder acceptance, and therefore, recognition of the available benefits. Maximum uptake may also initially be limited by intellectual property rights. In the longer term, uptake may also be limited to the proportion of vehicles undertaking driving tasks requiring constant 'stop-start' driving, which represent the sector where the greatest efficiency gains can be realised. This particular assessment thus restricts the likely market for the technology to rigid trucks undertaking urban freight distribution and service provision tasks (e.g. waste collection).

The 'in sequence' abatement for this option has been estimated at about a 1 Mt per annum contribution for 2050 (limited for this scenario by the restriction of the market to urban rigid trucks undertaking particular tasks); and with the maximum abatement potential estimated for this technology as an individual option at about 1.6 Mt CO_2 per annum by 2050 (higher due to truck fuel use already being substantially reduced, for the lower row of the assessment table's residual 'market emissions', by the options in the previous steps of the aggregate package implementation, and to the savings fraction for the 'in sequence' estimate being reduced to allow for possible overlaps with other options' effects – i.e. from the 0.2 savings value assigned to the technology when considered in isolation from other technology/efficiency options).

Note that there is probably considerable interaction or overlap between this technology and other possible efficiency measures such as encouraging eco-friendly driving or mass electrification of the urban truck fleet. As an example, if 'eco-driving' is implemented prior to regenerative braking, then regenerative braking may not have as large an impact as initially expected due to reductions in average braking behaviour.

Electric trucks

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Electric trucks	0.30	Urban rigids	9.1	0.75	2.0
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Electric trucks	0.30	Urban rigids	6.6	0.75	1.5

As for the regenerative braking option, this particular step of the assessment (adding significant use of electric trucks to the fleet) restricts the assumed market for the technology to rigid trucks undertaking urban tasks – which results in abatement values for this option of about 1.5 Mt CO_2e per annum by 2050 for abatement contribution 'in sequence' (as part of the Aggregate ALCTF scenario, assuming a net eventual adoption fraction for such vehicles of about 0.3) and around 2 Mt when considered as an individual or stand-alone option.

As detailed for electric light vehicles, it has been assumed that the future supply of Australian electricity strongly decarbonises in these projections (where the decarbonisation rate assumed in Treasury's 'core policy scenario' is given in *Strong Growth, Low Pollution,* http://www.treasury.gov.au/carbonpricemodelling/content/default.asp); and the calculated emission savings would be substantially reduced if 2050 electricity generation was still primarily from the current electricity mix.

Biofuels for heavy vehicles – trucks

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Fuel technology	Biodiesel	0.70	Trucks	36.1	0.65	16.4
'In sequence' calculated contribution to aggregate abatement						
Fuel technology	Biodiesel	0.75	Trucks	27.9	0.65	13.6

The next step in the (Table 4) sequence for the options aggregation scenario then assumes most of the remaining non-electric heavy vehicles run on biofuels/biofuel blends by 2050. For this scenario, most of this use is assumed to be due to biodiesel, both from a range of currently available sources (1st generation biofuels) and especially from projected future feedstock materials (2nd generation biofuels).

Depending on the feedstock, estimated likely abatement potential for biofuels covers a wide range, typically spanning savings fractions of about 0.3 to 0.9 (e.g. biodiesel can be derived from a variety of food crop feedstocks, from specialised energy crops – such as pongamia, from waste oils, or from algal biomass). A mid-range abatement fraction of 0.65 has been chosen for this scenario, where (as for light vehicles) representative biofuel emission factors (allowing for all the upstream emissions from the feedstock and fuel production stages) are provided in the CSIRO journal article:

Farine et al. (2011), An assessment of biomass for bioelectricity and biofuel, and greenhouse gas emission reduction in Australia, *Global Change Biology Bioenergy.*

This part of the options' aggregate package is estimated to generate a 2050 abatement contribution of close to 14 Mt per annum (FFC CO_2e); or slightly over 16 Mt per annum abatement when considered as a stand-alone or individual option, again assuming that supply constraints do not limit Australian biodiesel use by the road transport sector to volumes below this level of implied consumption.

As discussed for the light vehicle biofuels option, these truck scenarios place some limits on total biofuel supply/use, based on CSIRO assessments of likely future availability of domestic biofuels (i.e. estimates in Farine et al. 2011 on the future volumes of biofuel that can potentially be supplied annually by sustainable domestic production) – where it is assumed that annual abatement is restricted to between 1.5 to 2 times the amount CSIRO has estimated for the future as feasible from likely sustainable Australian feedstock availability (i.e. allowing for significant extra biofuel volumes to be potentially supplied from imports). The estimated supply limits lead to the assumed adoption levels for this assessment, of an 80 per cent market share as part of the aggregate scenario (giving a net adoption fraction of 0.75, after allowing for roughly 5 per cent market penetration in the base case projections) and of a 75 per cent market share as a stand-alone option (giving a net adoption fraction of 0.7, after allowing for the base case level of biofuel use).

Aircraft technologies

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh/Fuel technology	Technology advances	1.00	Domestic aviation	17.4	0.30	5.2
'In sequence' calculated contribution to aggregate abatement						
Veh/Fuel technology	Technology advances	1.00	Domestic aviation	17.4	0.30	5.2

Various emission abatement options for the aviation sector are canvassed within a Pew Center report covering possible aircraft technology improvements (http://www.pewclimate.org/docUploads/aviation-and-marine-report-2009.pdf, *Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies,* McCollum, Gould & Greene 2009), finding (see http://www.pewclimate.org/technology/factsheet/Aviation):

> 'A combination of operational practices, lower-carbon fuels, and higher aircraft fuel efficiency could reduce annual greenhouse gas emissions from global aviation by more than 50 per cent below 'business-as-usual' projections...
> Over the long term, advanced propulsion systems, utilization of lightweight materials, and improved aerodynamics and airframe designs hold the promise of further reducing aviation emissions...
>
> Aircraft efficiency technologies reduce the amount of fuel aircraft use per unit of distance travelled. Several technological improvements exist to improve aircraft aerodynamics, such as applying laminar flow control to an aircraft to reduce drag and, as a result, fuel consumption. More radical innovations include blended wing body aircraft that not only reduce drag but allow the entire aircraft to generate lift, as opposed to just the wings. More fuel-efficient engines and incorporation of super-lightweight materials, such as fibre-metal laminate, into the airframe offer additional avenues to improving aircraft efficiency... Technological advances offer the potential for...significant reductions. Current trends in aviation efficiency improvements are expected to continue; the efficiency of the U.S. and global aircraft fleets will continue to improve as older, less efficient aircraft are retired and then replaced with new, more efficient aircraft. Under 'business as usual' a projected 30 per cent decrease in aviation energy intensity will be achieved by utilizing currently known technologies: more efficient propulsion systems (engines), advanced lightweight materials, and improved aerodynamics (e.g., winglets, increased wingspans). Added support through government sponsored research and development (R&D) and other policy interventions could yield an additional 35 per cent reduction below BAU emissions in 2050. Much of this 35 per cent would come from application of the more ambitious and therefore riskier technological alternatives. Blended wing body or other innovative airframes, for example, could reduce fuel consumption by as much as 32 per cent when compared to an Airbus A380 (a currently operating state-of-the-art aircraft model). Advanced laminar coatings that reduce drag could increase fuel efficiency by a further 16.5 per cent.'

CSIRO's recent report on fuel use within the Australian aviation sector – for their recent Sustainable Aviation Fuel Road Map study (*Flight path to Sustainable Aviation*, http://www.csiro.au/resources/sustainable-aviation-fuel-report.html, CSIRO 2011) states that:

> 'New, more efficient aircraft together with improved aircraft operations and airspace management offer the most immediate way to reduce aviation's environmental impact and potentially halve global aviation fuel intensity (the fuel required per passenger kilometre) over the long term'.

CSIRO 2011 reproduces (as Table 2, pg.13) International Energy Agency (IEA 2009b, *Transport, energy and CO_2: moving towards sustainability*) assessments that also find potential fuel efficiency increases of 40-50 per cent as feasible.

Table 9: Summary of global potential for reducing fuel intensity in aviation

Type of improvement	Fuel intensity reduction relative to existing fleet
Airframe aerodynamics	20-30 per cent
Airframe light-weighting	20-30 per cent
Engine technologies	15-20 per cent
Air traffic management and operations	7-12 per cent
Total	40-50 per cent

Source: Table 2 of CSIRO 2011, quoting IEA (2009b) data.

Note: The total accounts for non-additive effects of combining measures. Local prospects for the listed improvements will differ from the global average due to differing fleet and airport operational conditions.

Some of the new technologies will probably have air safety implications and could require very long lead times for suitable development and testing.

Assuming a savings fraction of 0.3 for aircraft technology enhancement (relative to the base case efficiency improvements), the estimated 2050 abatement for civil domestic aviation comes to slightly above 5 Mt of FFC direct CO_2 equivalent per annum (for both the aggregate scenario contribution and the individual abatement potential, since this is the first option in the aggregation sequence to feature domestic aviation activity).

Note that most of the aviation emission values in this report – i.e. in the analysis presented in the aviation option assessment tables – would be almost twice as large if given in terms of **total** CO_2 equivalent emission terms, i.e. including both direct and indirect climatic impacts due to aviation activity, instead of the usual practice of solely **direct** CO_2 equivalents – which, as discussed in the section 'Base case emission trends', typically does not fully capture the high-altitude effects of some aircraft emissions. Allowing for such indirect effects makes abatement from aviation an even more significant component of overall efforts to restrict growth in transport emissions. See Chapter 5 of *Long-term Projections of Australian Transport Emissions: Base Case 2010*, BITRE 2010,

http://www.climatechange.gov.au/publications/projections/~/media/publications/projections/bitre-transport-modelling-pdf.pdf, and BITRE (2009) Working Paper 73, for more details on such issues.

Aviation alternative fuels – biofuels

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Fuel technology	Bio-fuels	0.75	Domestic aviation	17.4	0.60	7.8
'In sequence' calculated contribution to aggregate abatement						
Fuel technology	Bio-fuels	0. 85	Domestic aviation	12.2	0.60	6.2

In partnership with the major regional airlines, aircraft and engine manufacturers and other stakeholders, CSIRO's recently completed road map study *(Flight path to Sustainable Aviation*, http://www.csiro.au/resources/sustainable-aviation-fuel-report.html, CSIRO 2011) examines the issue of alternative fuel use for the Australian aviation sector. This CSIRO study considers that:

> 'The only alternative fuel which can meet all of the environmental, economic and technical challenges is sustainable aviation fuel derived from biomass (non-food parts of crops, plants, trees, algae, waste and other organic matter). Australia and New Zealand are strongly positioned to incorporate sustainable aviation fuel into the aviation fuel mix.'

Such bio-derived jet fuel should be suitable for a wide range of civil and military aviation operations. For reference, a summary of the typical amounts of military fuel used each year – and the fuel type specifications required – are given in: http://anao.gov.au/~/media/Uploads/Documents/2001%2002_audit_report_44.pdf , where the Australian Defence Forces account for significant annual volumes of aviation turbine fuel use, and will retain considerable interest in aviation biofuel developments. The Defence Science and Technology Organisation was one of the organisations involved in the above-mentioned CSIRO study.

The CSIRO road map study anticipates that there could be sufficient biomass (non-food, sustainable) feedstock available in Australia to supply around 40 per cent of jet fuel needs by 2020 and fully cover Australian aviation fuel needs by 2050. For this particular scenario it is assumed that various operational factors (such as several different industries competing for biofuel sales/resources) will limit eventual take-up to slightly below the full aviation fuel market (with maximal adoption assumed here at around 80 per cent of 2050 base case Avtur demand).

Depending on the feedstock, estimated likely abatement potential for biofuels covers a wide range, typically spanning savings fractions of about 0.3 to 0.9, e.g. see details of the CSIRO methodology, given in Sustainable Aviation Fuels Road Map: Data assumptions and modelling (Graham et al., (2011) which provides emission analysis for bio-derived jet fuels based on emission factors from: Stratton, R.W., Wong, H.M. and Hileman, J.I. (2010), *Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels:* PARTNER Project 28, report Version 1.1, Report No. PARTNER-COE-2010-001. Partnership for Air Transportation, Noise and Emissions Reduction.

Such abatement options for the aviation sector are also mentioned in the Pew Center report referenced previously: http://www.pewclimate.org/docUploads/aviation-and-marine-report-2009.pdf, *Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies* (McCollum, Gould & Greene 2009) which finds (see http://www.pewclimate.org/technology/factsheet/Aviation):

> 'A combination of operational practices, lower-carbon fuels, and higher aircraft fuel efficiency could reduce annual greenhouse gas emissions from global aviation by more than 50 per cent below 'business-as-usual' projections... Aggressive implementation of lower carbon fuels could improve that outlook considerably by replacing a larger share of traditional jet fuel more quickly... Alternative fuels have lower net GHG emissions than traditional petroleum-based aircraft fuel. Biofuels, Fischer-Tropsch fuels, and liquid hydrogen could all present feasible alternatives in the future. While these fuels do not present an immediate alternative, their adoption presents a long-term path toward lower carbon flight...
> While a number of technologies exist to produce alternative fuels, it is unclear at this time which technologies will prove viable in the long term. Conservatively, these alternative fuels could provide an additional 24 per cent emission reduction against a BAU scenario.'

For the scenario assessed here, a fairly conservative biofuels savings fraction of 0.6 is assumed, resulting in an estimate for 2050 aggregate abatement contribution of slightly above 6 Mt per annum (FFC direct CO_2 equivalent, off residual fuel use emissions by the civil domestic aviation sector); with the individual option assessment higher at around 8 Mt per annum (after allowing for around 5 per cent biofuel market penetration, for the base case projections, in the values for net adoption fraction).

Domestic shipping efficiencies

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh/Fuel technology	Technology advances	1.00	Domestic shipping	2.3	0.30	0.7
'In sequence' calculated contribution to aggregate abatement						
Veh/Fuel technology	Technology advances	1.00	Domestic shipping	2.3	0.30	0.7

Mandatory measures to reduce emissions of greenhouse gases from international shipping were adopted by the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO), when it met during July 2011, representing the first ever mandatory global greenhouse gas reduction regime for an international industry sector (see http://www.imo.org/MediaCentre/PressBriefings/Pages/42-mepc-ghg.aspx). Amendments to marine pollution regulations (for the prevention of air pollution from ships) add new regulations on energy efficiency for ships to make mandatory the Energy Efficiency Design Index (EEDI), for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. Adoption of the Energy Efficiency Design Index and CO_2 emissions standards for international ships are likely to influence adoption of new technologies by Australia's domestic fleet, expected to result in average CO_2 emission reductions, over the longer term of at least 25 per cent (relative to the business-as-usual case).

A detailed assessment of the emissions potential for various technical and operational measures within the maritime sector is supplied by the recent DNV report (DNV 2010, *Pathways to low carbon shipping - Abatement potential towards 2030*), noting that:

> 'In June 2009 DNV issued the first Pathway to Low Carbon Shipping which demonstrated the potential to reduce the CO_2 emission of the existing fleet by 15 per cent in a cost efficient manner. In this second Pathway to Low Carbon Shipping DNV has analysed the projected fleet in 2030. The study demonstrates that CO_2 emissions by 2030 can be reduced by 30 per cent below baseline in a cost-effective way, and by almost 60 per cent if all the identified measures are included. While there is no single measure which could make it all happen, the aggregated effect of all the measures is significant. This will ensure an industry that operates in a more energy efficient manner and also accepts its share of the common responsibility to reduce CO_2 emissions.'

The DNV report presents a marginal CO_2 reduction cost curve for shipping efficiency, evaluating the cost per unit CO_2 averted by a wide range of possible options across the world shipping fleet by 2030; where substantial levels of abatement are estimated to be available at net cost reductions (DNV 2010, pg. 3).

For shipping potential, another recent summary of available emission reduction options is given in the Pew Center report: http://www.pewclimate.org/docUploads/aviation-and-marine-report-2009.pdf, *Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies* (McCollum, Gould & Greene 2009, for the Pew Center on Global Climate Change) which finds (see http://www.pewclimate.org/technology/factsheet/MarineShipping):

> 'Replacing heavy fuel oil with less carbon-intensive marine diesel oil or liquefied natural gas could result in GHG reductions in the near to medium term. Other options include alternative energy sources, such as wind power (from sails) or biofuels. Longer-term opportunities include powering ships with solar photovoltaic cells and hydrogen fuel cells.
>
> Applying the full range of mitigation strategies described above could reduce GHG emissions from global shipping by as much as 62 per cent below 'business-as-usual' (BAU) projections in 2050,

which would mean global marine shipping emissions would be at roughly today's level at mid-century despite an expected doubling in shipping volume ...

Operational changes, such as reducing ship speeds, optimizing ship turnaround times by streamlining port logistics, and tailoring shipping routes to real-time weather and ocean current conditions are already expected to produce significant efficiency gains under 'business as usual' due to non-climate-related factors, such as rising fuel prices. With additional support through policy interventions, incremental operational changes could reduce GHG emissions by an estimated 27 per cent below BAU projections by 2025.

Advances in shipping technology hold the potential for additional GHG reductions. Larger ships are more efficient than smaller ones. For example, doubling the size of a vessel could increase energy efficiency by as much 30 per cent. Such changes in ship design and propulsion could further reduce GHG emissions by 17 per cent below BAU projections for mid-century.

Only a small degree of switching to alternative fuels is projected under 'business as usual'. Replacing heavy fuel oil with modified diesel oil, a slightly less carbon-intensive fuel, could reduce CO_2 emissions by 4 to 5 per cent. Shifting to liquefied natural gas could reduce GHG emissions by as much as 15 per cent. When combined with other alternative fuel sources, such as wind power (sails) or biofuels, switching to alternative fuels could yield reductions of 38 per cent below BAU GHG emissions projections by 2050.'

This scenario assumes that appropriate incentives would be capable of realising in the order of 15 per cent reductions in base case shipping emissions from both ship re-design and other operational (port/route) efficiencies (i.e. above BAU efficiency gains, where the base case projections already incorporate around a 10-20 per cent fuel efficiency improvement for coastal shipping over the next couple of decades).

That is, an aggregate emission saving factor of about 0.3 has been assumed to apply to the coastal fleet by 2050 – from a combination of larger average ship sizes, better hull design and other technological improvements (e.g. use of new-generation sails or fuel cells), and optimised shipping logistics and port management practices – resulting in a 2050 abatement estimate of about 0.7 Mt per annum (FFC direct CO_2e, for both assessment table rows, since this is the first option in the aggregation sequence to affect domestic maritime activity).

Biofuels for the maritime sector

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Fuel technology	Bio-fuels	0.85	All water craft	4.4	0.65	2.4
'In sequence' calculated contribution to aggregate abatement						
Fuel technology	Bio-fuels	0.85	All water craft	3.7	0.65	2.0

This next step in the aggregation sequencing refers to greater biofuel use in the maritime sector (in particular, biodiesel and hydrogen sourced from renewable generation). Potentials for such alternative fuel use are described in the afore-mentioned Pew Center report: http://www.pewclimate.org/docUploads/aviation-and-marine-report-2009.pdf, *Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies* (McCollum, Gould & Greene 2009) which finds (see http://www.pewclimate.org/technology/factsheet/MarineShipping):

> 'Replacing heavy fuel oil with less carbon-intensive marine diesel oil or liquefied natural gas could result in GHG reductions in the near to medium term. Other options include alternative energy sources, such as wind power (from sails) or biofuels. Longer-term opportunities include powering ships with solar photovoltaic cells and hydrogen fuel cells.
>
> Applying the full range of mitigation strategies described above could reduce GHG emissions from global shipping by as much as 62 per cent below 'business-as-usual' (BAU) projections in 2050, which would mean global marine shipping emissions would be at roughly today's level at mid-century despite an expected doubling in shipping volume ...
>
> Only a small degree of switching to alternative fuels is projected under 'business as usual'. Replacing heavy fuel oil with modified diesel oil, a slightly less carbon-intensive fuel, could reduce CO_2 emissions by 4 to 5 per cent. Shifting to liquefied natural gas could reduce GHG emissions by as much as 15 per cent. When combined with other alternative fuel sources, such as wind power (sails) or biofuels, switching to alternative fuels could yield reductions of 38 per cent below BAU GHG emissions projections by 2050.'

This scenario assumes that there is substantial availability of (renewably-sourced) biofuels by 2050 capable of serving as large-scale replacements for the conventional marine fuels currently used in coastal shipping. Depending on the feedstock, estimated likely abatement potential for biofuels covers a wide range, typically spanning savings fractions of about 0.3 to 0.9; where a mid-range abatement fraction of 0.65 has been chosen for this scenario.

With maximal adoption assumed here at around a 90 per cent market share (resulting in a net adoption fraction of 0.85 after allowing for about 5 per cent biofuel use in the base case projections), 2050 abatement potential is estimated at about 2.4 Mt (FFC direct CO_2e) per annum (with approximately half due to domestic shipping replacing marine distillate with biodiesel derivatives and half due to smaller craft replacing gasoline with ethanol blends). The 'in sequence' abatement estimate (operating off the somewhat lower residual market emissions) comes to about 2 Mt per annum.

Rail efficiency

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Technology advances	1.00	All rail	6.3	0.15	0.9
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Technology advances	1.00	All rail	6.3	0.15	0.9

For rail transport's first part of the aggregate options package, it is assumed that increased penetration of a range of energy saving technologies – such as regenerative braking (or other storage techniques like flywheels), fuel cells or heat exchangers (to make use of waste heat produced by traction) – have the capability to reduce base case rail emissions by the order of 15-20 per cent over the longer term.

For a variety of assessments of possible rail efficiency improvements, see the results of the *Energy Efficiency Technologies for Railways* project available on the International Union of Railways (2011) website at: http://www.railway-energy.org/tfee/index.php?ID=210&SEL=210&RESET=false&FREEFIELD=Energy%20efficiency%20(single%20vehicles).

This part of the aggregate scenario has estimated 2050 abatement of close to 1 Mt per annum (off the total rail sector's FFC CO_2 equivalent emissions).

Biofuels for railways

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Fuel technology	Bio-fuels	0.85	Non-electric rail	5.4	0.65	3.0
'In sequence' calculated contribution to aggregate abatement						
Fuel technology	Bio-fuels	0.85	Non-electric rail	4.4	0.65	2.4

Similarly to the maritime sector assessment, this next step for the rail sector in the options sequence, assumes that there will be substantial availability of renewably-sourced biodiesel (or hydrogen) by 2050 that can serve as a large-scale replacement for the conventional diesel fuels currently used in non-electric locomotives.

For this scenario, a mid-range abatement fraction of 0.65 has again been chosen for FFC biofuel emission reductions; leading to a 2050 'individual' abatement estimate of about 3 Mt per annum (with maximal adoption assumed here at around a 90 per cent market share, resulting in a net adoption fraction of 0.85 after allowing for about 5 per cent biofuel use in the base case projections). The 'in sequence' abatement estimate (operating off the lower residual market emissions) comes to about 2.4 Mt (FFC direct CO_2e) per annum for 2050.

Bus fuel efficiency

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh/Fuel technology	Fuel efficiency advances	1.00	Buses	2.7	0.20	0.5
'In sequence' calculated contribution to aggregate abatement						
Veh/Fuel technology	Fuel efficiency advances	1.00	Buses	2.7	0.20	0.5

As for trucks, there is assumed to be substantial fuel efficiency improvements technically possible, across the commercial bus fleet, over the medium to longer term.

The range of technologies assumed in earlier aggregation steps to gain significant penetration into the truck fleet – such as improvements to engine combustion efficiency, lowering rolling and aerodynamic resistance, and use of regenerative braking – are assumed capable of reducing bus emission rates by at least 20 per cent below the base case trends. Further enhancement of natural gas vehicles could also play a part in such advances (especially with CNG use already being significant for urban buses).

For this step in the aggregate package of options (the first in the Table 4 list for buses), 2050 abatement has been estimated at around 0.5 Mt per annum.

Electric buses

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle technology	Electric buses	0.35	Urban Buses	1.9	0.80	0.5
'In sequence' calculated contribution to aggregate abatement						
Vehicle technology	Electric buses	0.35	Urban Buses	1.9	0.80	0.4

As for other heavy vehicles (trucks), major electrification of buses is assumed to be largely restricted to urban operations/routes – which results in emission abatement values of about half a megatonne (of full fuel cycle direct CO_2 equivalent) per annum by 2050 (with maximal adoption of urban electric buses assumed here at around the 50 per cent market share, resulting in a net adoption fraction of about 0.35 relative to the base case projections, after allowing for the amount of electric bus use in the base case scenario). As part of the aggregation assessment, the contribution of further bus electrification has the slightly lower estimate of 0.4 Mt per annum for 2050.

As for other electric vehicle types, it is assumed that the future supply of Australian electricity strongly de-carbonises in these projections (with the de-carbonisation rate assumed in Treasury's 'core policy scenario' given earlier). Again, the calculated emission savings would be substantially reduced if 2050 electricity generation was still primarily from the existing electricity fuel mix.

Biofuels for heavy vehicles - buses

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Fuel technology	Bio-fuels	0.82	Buses	2.5	0.65	1.4
'In sequence' calculated contribution to aggregate abatement						
Fuel technology	Bio-fuels	0.82	Buses	1.4	0.65	0.7

The next step for buses in the aggregation sequence then assumes most of the remaining non-electric commercial buses and coaches run on biofuels by 2050. For this scenario, the major part of this use is assumed to be due to biodiesel, both from a range of currently available sources (1st generation biofuels) and projected future feedstock materials (2nd generation biofuels).

Depending on the feedstock, estimated likely abatement potential for biofuels covers a wide range, typically spanning savings fractions of about 0.3 to 0.9; and as for trucks, a mid-range abatement fraction of 0.65 has been chosen for this scenario (i.e. again using estimates in Farine et al. 2011).

This part of the options aggregation is estimated to generate 2050 abatement of about 0.7 Mt of CO_2 equivalent per annum; or about 1.4 Mt abatement potential when considered as an individual option (with maximal adoption assumed here at around a 90 per cent market share, resulting in a net adoption fraction of 0.82 after allowing for about 8 per cent biofuel use in the base case projections).

2. PRICE SIGNALS

This next of the seven categories (that the Aggregate Scenario has been subdivided into, for the evaluation calculations), does not have as high an overall abatement potential as the 'Vehicle and fuel technology' category – but 'Price Signals' could provide a means of obtaining major cuts to transport sector emissions. This is due to such options not only offering their own intrinsic abatement, but also to their actions as enablers of other options (such as technology innovation take-up) by encouraging energy-saving behaviour.

Also, the aggregation analysis does not tend to consider possible *rebound effects* (which can often reduce the net advantages of energy-saving measures due to some extra travel being generated by the resulting fuel cost savings), since the introduction of such a full package of options, including a range of appropriate pricing signals and with other travel demand management aspects, should serve to control or minimise any potential rebound travel. Note that the significance of rebound effects is already likely to be relatively low over the long term that these projections deal with, since – as discussed in the report's section on the base case emission projections – many personal travel trends are likely to be comparatively saturated in the future, lessening the incentive for any extra travel, even if average transport costs do decline.

Urban road pricing

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Variable pricing	Road/ congestion pricing	0.70	Urban light vehs	43.7	0.23	7.0
Variable pricing	Road/ congestion pricing	0.60	Urban trucks	14.3	0.10	0.9
'In sequence' calculated contribution to aggregate abatement						
Variable pricing	Road/ congestion pricing	0.70	Urban light vehs	11.3	0.23	1.8
Variable pricing	Road/ congestion pricing	0.60	Urban trucks	4.9	0.10	0.3

Urban road pricing across the major Australian cities offers significant potential for emission reductions. The results presented for this option (the first of the set of the abatement category *Price Signals*), the introduction of city-wide congestion pricing to all major centres, are based on a variety of BITRE modelling studies into average Australian traffic conditions and the social/environmental impacts of congestion (e.g. see BTCE 1996a, *Traffic Congestion and Road User Charges in Australian Capital Cities*, Report 92; and BTRE 2007, Estimating urban traffic and congestion cost trends for Australian cities, Working Paper 71, http://www.bitre.gov.au/publications/49/Files/wp71.pdf and Chapter 18 of Report 94 *Transport and Greenhouse: Costs and options for reducing emissions*, BTCE 1996b).

These studies generally analysed optimal road user charges – with cost values varying by location and time of day – and typically dealt with scenarios charging motorists in the order of 10 to 30 cents per kilometre for the larger Australian capitals, averaged over daily travel (with maximal charges potentially being over a dollar per kilometre while driving through the most congested areas), and with averages of about 2 to 8 cents per kilometre for smaller centres.

This level of road user charges is estimated to result in a potential 2050 reduction, across the urban vehicle fleet, of about 8 Mt per annum. This is primarily due to reduced car travel demand, some modal shift to public transit or non-motorised travel, and improved fuel efficiency of peak hour traffic (with reduced congestion levels meaning fewer interruptions to freely flowing driving conditions) – where per vehicle advantages from such a pricing measure are assumed to be less for freight vehicles (which typically do not travel in peak traffic periods to the same extent as light vehicles).

The lower residual market emissions for the 'in sequence' calculations (with the options higher on the Table 4 ordering already having reduced vehicle emissions by over 70 per cent from the base case levels) leads to the estimates for 2050 aggregate abatement contribution totalling about 2 Mt CO_2e per annum (and likely forming an important part of the incentives required for achieving some of the urban mode-switching and further travel reduction options dealt with in later sections of the report).

Pay-As-You-Drive vehicle pricing

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Pay-as-you-drive	Distance based charges	1.00	All light vehicles	72.9	0.08	5.5
Pay-as-you-drive	Distance based charges	1.00	Trucks	36.1	0.03	1.1
'In sequence' calculated contribution to aggregate abatement						
Pay-as-you-drive	Distance based charges	1.00	All light vehicles	17.0	0.08	1.3
Pay-as-you-drive	Distance based charges	1.00	Trucks	14.0	0.03	0.4

This next variable pricing option envisages a nationwide program implementing distance-based vehicle charges – scaled where appropriate to allow for the emissions intensity of the type of vehicle – and incorporating utilisation-based (per kilometre) fees for certain vehicle operating costs (such as registration and insurance).

As summarised by the Victoria Transport Policy Institute (http://www.vtpi.org/tdm/tdm10.htm, VTPI 2011):

> 'Distance-Based Pricing (also called Pay-As-You-Drive, Mileage-Based and Per-Mile pricing) means that vehicle charges are based on how much a vehicle is driven, so the more you drive the more you pay and the less you drive the more you save. Such fees tend to be more economically efficient and fair than existing pricing practices (Market Principles). Converting fixed costs into distance-based charges (called Variabilisation, see INFRAS 2000) gives motorists a new opportunity to save money when they reduce their mileage.'

The primary examples of distance-based vehicle charges are Pay-As-You-Drive insurance (where annual premiums are reduced for motorists driving less than average, as their accident exposure rates are typically proportionately reduced) and VKT-based registration fees (where vehicle licensing and registration fees are prorated according to annual travel, and which can be readily structured to have more favourable fee schedules for fuel-efficient vehicles). Various other vehicle purchase and ownership costs can be converted into variable fees – and such measures can be supported by 'feebate' schemes that charge more highly for the purchase of less-fuel-efficient vehicle types (further encouraging emission reductions – see Langer 2005, *Vehicle Efficiency Incentives: An Update on Feebates for States*, and Bunch & Greene 2010, *Potential Design, Implementation, and Benefits of a Feebate Program for New Passenger Vehicles in California: Interim Statement of Research Findings*). Schemes such as feebates, with differential vehicle purchase duties, can be an important element of eventual fleet CO_2 reductions, especially if the price differences are large enough to encourage most motorists to purchase the best environmentally performing vehicle that otherwise meets their requirements. However, effects on total CO_2 released over the life of the vehicle tend to be more significant for pricing targeting vehicle operation/use (such as distance-based charges) than upfront charges like feebates (and since there is already movement by some jurisdictions towards such fees – e.g. the ACT Government has introduced the 'Green Vehicles Duty Scheme', with differential stamp duty costs for new light vehicles to provide an incentive for the purchase of low emission vehicles – a certain amount of such measures' possible effects are already included in the base case projections).

The effects of the various pricing possibilities will vary by the charging level, how the schemes are implemented and the type of vehicle the fees are being levied on. Based on the summary research presented by the VTPI (2011), savings fractions across the light vehicle fleet in the order of 5-10 per cent are assumed feasible (especially if accompanied by suitable feebate-type measures); and with around 2-5 per cent reductions assumed possible for heavy vehicles.

This next step in the *Price Signals* category, as part of the options aggregation list, is estimated to generate 'in sequence' 2050 abatement contributions of about 1.7 Mt per annum. The 2050 abatement potential when considered as an individual option (i.e. without the large preceding reduction in the market emissions by options higher in the Table 4 ordering) is estimated to be about 6.6 Mt of CO_2 equivalent per annum.

Urban parking charges

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Commuter travel	Parking charges	1.00	Urban light vehs	43.7	0.01	0.4
'In sequence' calculated contribution to aggregate abatement						
Commuter travel	Parking charges	1.00	Urban light vehs	8.7	0.01	0.1

The estimates presented for this option, increased urban parking charges, are based on the results of Chapter 7 in BTCE Report 94 (*Transport and Greenhouse: Costs and options for reducing emissions*, BTCE 1996b).

In Report 94, a scenario was analysed under which charges would be adopted for all-day parking throughout all business areas of the Australian capital cities (with representative results being provided for charges averaging $12 per day). With the majority of urban full day parking being charged (not just that in CBDs and other major hubs/centres), commuter travel would be the trip type most affected.

This level of extra parking charges is estimated to result in a likely 2050 abatement of about 0.1 Mt per annum (in the aggregation sequence, or about 0.4 Mt considered individually), primarily due to reduced car travel demand and modal shifts to public transit or non-motorised travel (and with some reductions in traffic congestion due to the changes in commuter travel behaviour).

Uncertainties remain over how much extra abatement could be generated by even higher levels of urban parking charges.

3. REGULATION

Moderate fuel efficiency standards

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh design/ performance	Moderate CO_2 standards	1.00	Light vehicles	72.9	0.10	7.3
'In sequence' calculated contribution to aggregate abatement						
Veh design/ performance	Moderate CO_2 standards	1.00	Light vehicles	0.0	0.10	0.0

The Australian Government has announced that carbon dioxide emission standards will apply to the new light vehicle fleet from 2015 (see the Department of Infrastructure and Transport discussion paper (Commonwealth of Australia 2011d), *Light vehicle CO_2 emission standards for Australia: Key Issues – Discussion Paper – 2011*). The mandatory standards will form part of the Government's Clean Energy Future strategies – though, as noted earlier, since the design of this regulation is on-going, the possible effects of such standards (on transport sector emissions) are not included in the current base case projections. This option assessment considers potential emission abatement from imposing some new vehicle fuel/CO_2 intensity standards. However since the ALCTF process is essentially focussed on deriving the maximal possible outcome from a package of measures, the results given here do not have any direct bearing or relation to the upcoming 'mandatory CO_2 standards' policy (i.e. to any of the policy development considerations and consultative processes currently being undertaken by government agencies).

Based on the potential fuel efficiency improvements canvassed in the first of the Aggregate Scenario's options – i.e. the Vehicle Technology section assuming radical reductions in light vehicle fuel intensity – efficiency standards on new vehicles should have the capability of delivering significant CO_2 emission reductions over the medium to longer term (as the new more-efficient vehicles gradually replace the existing fleet).

Vehicle design standards targeting fuel (L/100km) or CO_2 emissions intensity are already enacted in many jurisdictions, including Europe and the US, and, as discussed, are currently being framed for Australia. Depending on their stringency, such CO_2 standards probably have the potential to reduce BAU emission trends by the order of 5-10 Mt per annum, while remaining within limits the ALCTF Workshop participants generally considered as achievable or 'moderate', and (based on BITRE vehicle fleet modelling of a range of possible settings for such standards) has been roughly estimated as having a feasible savings fraction, across the light vehicle fleet, of about 0.1 over the medium to longer term.

This assumed savings fraction (for 2050) leads to an estimate of approximately 7 Mt CO_2e per annum (for possible light vehicle abatement) when considered as an individual, or stand-alone, measure (i.e. independently of the extensive technology penetration assumed to have occurred within the first few options of the *Vehicle and Fuel Technology* category, at the head of the Table 4 listing). However, when considering abatement contribution as part of the Aggregate Scenario's order, the technology opportunities that would be used to meet such standards (e.g. such as covered by assessments like the afore-mentioned King Review) will have already been accounted for, as part of attaining the first steps of the aggregation (i.e. light vehicle electrification and radical fuel intensity reductions). That is, even though the 'in sequence' abatement has been set to zero here, it does not mean the standards are having no effect on emission levels – simply that by this stage in the aggregate calculation, whatever incentives (such as feebates) or other technology enablers (such as the CO_2 standards being considered here), that might have been required to achieve the energy efficiency improvements assumed in Table 4's initial steps, will have their abatement impacts already fully allowed for within the abatement values of the resultant technology options.

Even though enacting such national standards, especially over the shorter term, is quite likely to be important to actually achieving such radical CO_2 intensity reductions over the longer term, the Aggregate Scenario is primarily attempting to estimate maximal emission reduction potential across the Australian domestic transport sector – and abstracts, for now, many issues relating to likely barriers (such as up-front implementation costs) or required facilitation (such as necessary regulation levels).

Triples for B-doubles

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh design/ performance	B-triples	0.55	B-doubles	11.3	0.10	0.6
'In sequence' calculated contribution to aggregate abatement						
Veh design/ performance	B-triples	0.55	B-doubles	4.2	0.10	0.2

Since B-doubles were introduced in the 1980s, their high relative efficiency has enabled them to gradually capture more of the long-distance general freight market each year, and they now carry more road freight than any other truck combination. In the base case, this increasing market share has been assumed to continue, though with an upper bound – since B-doubles are Restricted Access Vehicles (i.e. can only operate on suitable government-approved routes, given their large size) – such that their current share of total tonne-kilometres (33 per cent of the national total for 2010), grows to 42 per cent by 2020 and 55 per cent by 2050 in the base case scenario projections (where the 'market emissions' value in the table relates to this portion of heavy vehicle traffic).

Even though B-doubles offer substantial energy savings over most available configurations (e.g. generally consuming at least 20 per cent less fuel per tonne-kilometre performed than a standard 6-axle semi-trailer), the approval of even larger trucks, on more routes than currently, should theoretically allow even greater fuel reductions (assuming any concerns with road safety can be successfully addressed). The widespread replacement of B-doubles with larger B-train or AB-train configurations (especially B-triples) is assessed by this option.

A B-triple or longer B-double should offer emission savings (per tkm) of around 10-15 per cent over a standard B-double (where the scenario evaluated here assumes that at most about half of the baseline B-double task is suitable for replacement by these even larger trucks). For this regulation change, the 'in sequence' 2050 abatement from this amount of freight transfer is estimated at about 0.2 Mt per annum (or approximately 0.6 Mt per annum when considered individually).

PBS-style trucks

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Veh design/ performance	PBS trucks	0.22	Trucks	36.1	0.10	0.8
'In sequence' calculated contribution to aggregate abatement						
Veh design/ performance	PBS trucks	0.22	Trucks	13.3	0.10	0.3

Two current regulatory mechanisms for increasing freight vehicle productivity are 'Performance Based Standards' (PBS) and the 'Intelligent Access Program' (IAP). These innovative schemes include aspects such as permitting longer and heavier vehicle combinations with access to new routes, small increases in axle loads and payload volume, and in some cases, entirely new vehicle designs.

Per vehicle emissions savings factors are assumed at 10 per cent, which is an estimate of the fuel savings derived from conversion from a conventional vehicle design to 'PBS-style' vehicle, in recognition of the productivity benefits. Since this assumption is based on the minimum change necessary to derive a transition to PBS-style vehicles, it could be considered conservative, and does not account for the improvement potential of other effects, which in some cases may be in excess of 20 per cent. Additionally, increased transition to road friendly suspensions (RFS) and other next generation active suspension technology could allow further axle load limit increases, which would increase the available emission savings factors (though such possible under-estimation of the potential savings fraction will be balanced to some extent by this option having some overlap with the previous option, B-triple take-up).

This step in the aggregation sequence is estimated to deliver an abatement contribution by 2050 of about 0.3 Mt per annum, with estimated abatement potential of about 0.8 Mt when considered individually. This relatively modest emission reduction is partially indicative of the inherent limits on increases in vehicle productivity (size and mass), as a direct result of the limits of existing road infrastructure.

Gross polluter control

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle performance	Gross polluter control	0.90	Non-elec vehicles	104.3	0.015	1.4
'In sequence' calculated contribution to aggregate abatement						
Vehicle performance	Gross polluter control	0.90	Non-elec vehicles	20.4	0.015	0.3

The worst 10 per cent of vehicles typically account for about half of the pollutant emissions from the light vehicle fleet. For examples of vehicle emission testing on the Australian fleet, see Federal Office of Road Safety (1996), *Motor Vehicle Pollution in Australia, Report on the National In-Service Vehicle Emissions*

Study and the 2009 *Second National In-Service Emissions Study (NISE2) Light Duty Petrol Vehicle Emissions Testing – Final Report* (Commonwealth of Australia 2009). This option considers using some manner of law enforcement (e.g. relying on roadside emission monitoring to identify highly-emitting vehicles) to require the repair or replacement of such grossly polluting vehicles (for discussion of such technology use, see Bluett, Dey and Fisher 2008, *Assessing Vehicle Air Pollution Emissions*, NIWA Client Report: CHC2008-001).

Totally rectifying the gross-polluter component of the current fleet would probably deliver significant improvements in urban air quality, and could offer potential reductions in the order of 5-10 per cent in total radiative effects levels due to light vehicle emissions – i.e. if counting all relevant gases, the indirect greenhouse gases (such as ozone-precursors, CO, NO_x and hydrocarbons) as well as the directly warming gases (such as CO_2, CH_4 and N_2O). As discussed previously, for comparability purposes, this report's assessment results use the current standard method of measuring CO_2 equivalent values (i.e. including only the *direct* greenhouse gases); though bearing in mind that for some situations (such as for aviation emissions and urban pollutants) this practice is less than fully comprehensive[6], and should the indirect gases be successfully accounted for (in future 'CO_2 equivalent' quantifications) then the estimated greenhouse abatement potential of measures such as this will be expanded.

In 'direct CO_2 equivalent' terms, repair of such gross-polluting vehicles probably offers in the range of 2-5 per cent average emission improvements for each vehicle serviced, due primarily to rectification of engine faults causing fuel consumption problems (e.g. see FORS 1996, *Motor Vehicle Pollution in Australia, Report on the National In-Service Vehicle Emissions Study*, which found that the worst-polluting 10 per cent of tested vehicles averaged fuel consumption reductions of over 5 per cent after tuning, and that an overall improvement of around 1.5 per cent was recorded across the whole test fleet after servicing).

This proportional reduction potential may reduce over time, as improving emission-control technology on new vehicles (required under the various Australian Design Standards) penetrates the fleet, not only gradually reducing total fleet output of CO, NO_x and hydrocarbons, but with monitoring technologies such as on-board diagnostics (OBD) possibly dramatically reducing eventual gross polluter occurrence (and thus the effectiveness of enforcement measures such as this option). As a rough allowance for such possibilities, the 2050 emission savings fraction has been discounted to an extent, to allow for the prospect of future improvements to pollutant-control systems reducing the likelihood of vehicles developing gross-polluter characteristics (and where the abatement potential will tend to be lessened by high volumes of vehicle electrification, as has been assumed in the first step of the Aggregate Scenario's options sequence).

If such an enforcement measure's appraisal solely provides for identification and servicing of the worst 10-20 per cent of the vehicle fleet, then abatement fractions lower than 1 per cent (reductions in direct CO_2 equivalent, across the full fleet) could be expected. However, this option assessment assumes that other probable flow-on effects (such as for a portion of the general fleet being encouraged to improve their vehicle maintenance and servicing routines/schedules, and for some acceleration of average fleet turnover – since some of the worst-condition vehicles will probably be incapable of meeting emission standards, even after affordable repair, and will have to be scrapped) lift the overall fleet savings fraction towards 2 per cent.

The assumed adoption fraction has not been set to a full value of 1, since it is envisaged that not every area will be covered by such roadside monitoring equipment, but that the emission measurements would concentrate on major thoroughfares.

The above assumptions result in a 2050 abatement contribution estimate of about 0.3 Mt per annum (FFC direct CO_2 equivalent) in the aggregation sequence, and a rough abatement potential of about 1.4 Mt per annum (FFC direct CO_2 equivalent) when considered individually.

[6] Note that for descriptions of representative differences, between 'CO_2 equivalent' emission values for particular transport activities, resulting from the two calculation methods (i.e. including solely the directly warming gases versus estimating the effects of both direct and indirect emission effects) see Chapter 5 of *Long-term Projections of Australian Transport Emissions: Base Case 2010* (BITRE 2010): http://www.climatechange.gov.au/publications/projections/~/media/publications/projections/bitre-transport-modelling-pdf.pdf.

4. URBAN TRANSPORT

Though many of the measures or option effects canvassed in other report sections overlap transport efficiency concerns within urban areas, this next category looks at a set of issues *dealing specifically* with reducing emissions from Australian urban transport.

Urban design

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Urban vehicle demand	Urban form/ design	0.50	Urban vehicles	58.0	0.15	4.3
'In sequence' calculated contribution to aggregate abatement						
Urban vehicle demand	Urban form/ design	0.50	Urban ve- hicles	13.3	0.15	1.0

This option considers changes, over the medium to longer term, to standard urban form – especially urban design or planning enhancements that focus on Australian cities having an appropriate co-location of functions (e.g. amenity, employment and living space) so that individuals are not required to travel as intensively, hence reducing average daily VKT and consequent CO_2 emissions. Attempts to gain such colocation or urban connection benefits (through techniques such as urban density increases or Transit-Oriented Development) are constrained by land availability and coordination of developers and will involve co-dependencies with a variety of other strategies; such as road pricing, parking availability/signals or otherwise promoting mode shifts. Note that the assessment values provided in this section relate solely to travel reduction outcomes (e.g. from reduced commuting and average travel distances resulting from suitable land-use aggregation), and do not include any extra CO_2 benefits possible from elements such as generated mode-switching (from private car use to public transit or non-motorised travel) or improved vehicle efficiency from traffic congestion reductions (since the abatement resulting from these outcomes is already dealt with, in separate option assessment steps).

According to the ITS United Kingdom Carbon Working Group, the implementation of an appropriate land use and transport planning framework could result in a reduction in UK greenhouse gas emissions of at least 2 Mt CO_2 by 2020:
http://www.tap.iht.org/objects_store/201005/itsuk_strategy_%20to_support_carbon_reduction_and_to_address_climate_change_issues_v1-3.pdf

The Garnaut Review (2008, http://www.garnautreview.org.au/pdf/Garnaut_Chapter21.pdf) provides data (Figure 21.8, derived from Kenworthy 2008 and Kenworthy & Laube 2001) demonstrating that, on average, European cities have around 40 per cent lower transport CO_2 emissions per capita than Australian cities (though this would be a combination of both lower average VKT per person and a greater proportion of urban public transport use or non-motorised travel).

Analysis by Newman and Kenworthy (such as provided in the Garnaut Review, Newman & Kenworthy 1989, and Newman, Kenworthy & Laube 1999) has examined, for many cities worldwide, the impacts of residential density on urban transport patterns; showing that, on the whole, higher population densities tend to be associated with lower rates of automotive fuel use.

Despite such apparent links between average urban density and resulting energy demands, Gray, Gleeson and Burke (2008, *Urban Consolidation and Household Greenhouse Emissions: Towards a Full Consumption Impacts Approach*) caution against focussing too narrowly on density and urban consolidation concerns, without fully gauging the effects of other facets (of urban design/planning) often crucial to actually obtaining net greenhouse benefits. In the context of describing the 'compact city ideal', they state (Gray, Gleeson and Burke 2008, pg.1) that:

> 'Planning influences urban form and structure (in Australia, primarily through metropolitan, land-use and transport plans). Urban consolidation is a common theme of current Australian metropolitan plans, and the theme that is, arguably, having the most tangible impact on the morphology of Australian cities.
>
> There is more to Australia's metropolitan plans than urban consolidation. Their visions reflect the compact city model, considered to be the ideal model of urban form and structure in Western planning. Its basic principles are urban containment, centralisation and consolidation (Frey 1999, Forster 2006). As a result:
>
>> In 20-30 years time, if the plans come to fruition, our major cities will be characterised by limited suburban expansion, a strong multi-nuclear structure with high density housing around centres and transport corridors, and infill and densification throughout the current inner and middle suburbs (Forster 2006, p. 179).'

As acknowledged by Newman and Kenworthy (1999), in addition to urban density, there are a range of other factors concerning urban form, land-use and structure (some of which will vary with or be dependent on underlying density patterns), that are essential for promoting lower travel volumes and lower overall car use. As summarised by Gray, Gleeson and Burke (2008, pg.3):

> 'Important features include: employment density and activity intensity (Mindali, Raveh and Salomon 2004, Chandra 2006), existence and spacing of employment and service centres (Mindali, Raveh and Salomon 2004, Holden and Norland 2005), local land use mix (Cervero and Kockelman 1997), and neighbourhood design and street layout (Handy, Cao and Mokhtarian 2006). Transport services are a critical accompaniment (Mees 2000). In sum, this prescription has been described as 'public transport friendly land use' (Rickwood, Glazebrook and Searle 2008, p. 20).'

That is, such features are typically part of, or closely aligned with, the full 'compact city' vision, but are not necessarily products of urban consolidation/densification alone. To demonstrate the risks of concentrating too exclusively on urban density, Gray, Gleeson and Burke (2008) go on to survey a range of research for Australian urban areas (such as Perkins et al. 2007). These studies appear to show, despite inner-city dwellers often having considerably lower vehicle or transport energy use than for the outer suburbs, that once full lifestyle and housing factors are considered their aggregate CO_2 generation per capita was generally higher than outer area residents. This leads Gray, Gleeson and Burke (2008) to contend that:

> 'A major research gap is the assessment of consolidation's impact in the context of the **full** greenhouse emissions and energy demands of household consumption. Full greenhouse emissions and energy demands include those generated in the production, delivery, and use of household goods and services as well as in the direct use of petrol, electricity and gas. It is these full impacts that matter for sustainability, though responsibility for their management rests with a number of actors and jurisdictions.'

In fact, in detailed research across Australia on such aggregate contributions to CO_2 emissions from all aspects of household consumption, Dey et al. (2007, *Household environmental pressure from consumption: an Australian environmental atlas*) find that:

> 'Any benefits from urbanisation, such as higher population densities in the inner cities leading to increased use of public transport, are completely over-ridden by the negative impacts of the additional consumption of the (affluent) inner-city areas. In each state and territory, the centre of the capital city is the area with the highest environmental impacts, followed by the inner suburban areas.
>
> Affluence is the dominant effect, even though urban living patterns offer many opportunities for efficiency and reduced environmental impacts, compared to more dispersed populations.'

One of the land-use management paradigms that attempt to address such concerns is termed 'Smart Growth'. As described by the Victoria Transport Policy Institute (VTPI 2011, http://www.vtpi.org/tdm/tdm38.htm):

> 'Smart Growth (also called New Urbanism and Location Efficient Development) is a general term for policies that integrate transportation and land use decisions, for example by encouraging more compact, mixed-use development within existing urban areas, and discouraging dispersed, automobile dependent development at the urban fringe. Smart Growth can help create more accessible land use patterns, improve transport options, create more livable communities, reduce public service costs and achieve other land use objectives. Smart Growth is an alternative to urban sprawl.'

Litman (2011, *Smart Growth Reforms Changing Planning, Regulatory and Fiscal Practices to Support More Efficient Land Use,* Victoria Transport Policy Institute) summarises some of the characteristics of 'Smart Growth', including:

- Higher density development, with clustered activities, and limiting urban fringe or greenfield growth patterns
- Mixed land-use, and attention to human scale details (such as smaller blocks and reduced road-space), including local access to amenities such as schools, shopping and parks – ideally accommodating walking access
- Support for multi-modal travel, especially integrating walking, cycling and public transit
- High connectivity (within and between city areas), including non-motorised networks
- Traffic calming, and layouts that emphasise public spaces.

Litman & Steele (2011, see also http://www.vtpi.org/tdm/tdm20.htm, Table 5) present a summary of analyses dealing with the typical impacts on transport of various changes to land use or urban form; such as increases to urban density or regional accessibility, greater 'centricity' or land use mix (residential, commercial, institutional), improved network connectivity and support for non-motorised travel, parking management and greater integration between development activities.

Across the range of available literature studies, evaluation of the possible advantages of urban design principles such as Smart Growth or Transit-Oriented Development suggest that implementing appropriate land-use changes to a low-density urban area has the capability of aggregate travel reduction (i.e. from reduced trip generation and shorter average journey lengths) of between 10-30 per cent.

For this assessment, it is assumed that those urban areas amenable to such design principles (here roughly assumed to be half of existing Australian urban areas) attain around a 15 per cent reduction in overall transport use (with a value chosen towards the lower end of the likely range since many Australian cities' forward plans already support such principles, so some such development/re-development can be expected to occur in the base case). This reduction in travel is essentially from co-location benefits (and which will provide some of the appropriate incentives for more pedestrians, cycling and public transit use, as evaluated in following option assessment sections).

The chosen savings fraction of 0.15 yields an estimated 2050 abatement potential (from vehicle trip reduction after co-location) of about 4.3 Mt CO_2e per annum (or about 1 Mt per annum as part of the aggregation sequence, with all the previous steps' reductions in the base emission levels).

The knowledge base is considered to be fairly high in this area, however there are challenges with implementation, with barriers in private funding, consumer behaviour, political will, planning of systems to incorporate sustainability and the planning of infrastructure (including land-use planning to enable co-modal, bi-modal and transport logistical hubs). These calculations are thus only roughly indicative, and changes to urban land-use/form could offer significantly larger emission reductions (over the longer term) if all implementation barriers can be successfully overcome.

Travel Demand Management – including urban telecommuting

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Public transit demand	Telecommuting	0.05	UPT	2.5	0.25	0.03
Urban vehicle demand	TDM, inc telecommuting	0.10	Urban light vehs	43.7	0.30	1.3
'In sequence' calculated contribution to aggregate abatement						
Public transit demand	Telecommuting	0.05	UPT	1.1	0.25	0.01
Urban vehicle demand	TDM, inc telecommuting	0.10	Urban light vehs	7.8	0.30	0.2

This option considers the greater use of telecommuting, supported by appropriate travel demand management (TDM) programs like TravelSmart, primarily to reduce the amount of CO_2 due to the journey to work in Australian cities. Note that, as for the previous option on *Urban Design*, the assessment values provided in this section relate solely to travel *reduction* outcomes (e.g. from reduced commuting trips due to increased telecommuting and from reduced discretionary travel following suitable TDM marketing campaigns), and do not include extra CO_2 benefits flowing from any generated mode-switching (i.e. from private car use to public transit or non-motorised travel, since abatement resulting from these outcomes is dealt with by separate option assessment steps).

The emission savings estimates for telecommuting promotion – aimed at urban commuters – are based partially on the results of Marinelli et al. (2010, Flexible Workplaces: Achieving the worker's paradise and transport planner's dream in Brisbane: http://www.patrec.org/web_docs/atrf/papers/2010/1874_006%20-%t20Marinelli&20Cleary%20Worthington-Eyre%20Doonan.pdf).

This Brisbane pilot found those who telecommuted reduced private travel (in vehicle kilometres) by around 31 per cent and public transport travel by about 25 per cent. By various approaches, the paper concluded that the order of 7-14 per cent of CBD workforces might be able to take up more flexible working practices of which telecommuting was one option (others assessed included alternative daily working times or a compressed working week).

Scaling this particular estimate to a full result for 'typical city-wide' responsiveness is somewhat problematic, given that CBD take-up of telecommuting may not be adequately representative of workers in other parts of the urban area; and even if characteristic, this study's estimated response group of 7-14 per cent covers three different flexible working arrangements, and it is not readily apparent how much of this aggregate would take up the specific option of telecommuting (where the other alternatives probably have some beneficial CO_2 impacts, but do not offer the same level of net trip reduction as telecommuting).

Commuting also only accounts for something like a third of total urban travel, and care has to be taken when assessing the effectiveness of telecommuting that total VKT impacts are covered (i.e. net travel outcomes, not just those due to journey to work reduction). For example, the Victoria Transport Policy Institute's discussion of using 'Telework' to substitute for physical travel (VTPI 2011, http://www.vtpi.org/tdm/tdm43.htm) considers telecommuting to have reasonable potential for VKT reduction, noting a 'telework program that reduces 10 per cent of vehicle trips may reduce 15 per cent of vehicle mileage if participants have longer than average commutes', while cautioning that its overall success can at times be quite limited, since:

> 'Although it tends to reduce peak-period trips, Telework does not necessarily reduce total vehicle travel unless it is implemented in conjunction with other travel reduction strategies. Vehicle travel reductions and energy savings may be partly offset in the following ways (Rebound Effects):

- Employees may use teleworking to move further from their worksite, for example, choosing a home or job in a rural area or another city because they know that they only need to commute two or three days a week. This may increase urban sprawl.
- Teleworkers often make additional vehicle trips to run errands that would otherwise have been made during a commute.
- Vehicles not used for commuting may be driven by other household members.
- Telecommuters may use additional energy for home heating and cooling, and to power electronic equipment.
- Improved telecommunications may increase people's long-distance connections, resulting in more travel.'

Such rebound travel effects are assumed to be minimal for this particular scenario, since the telecommuting increases envisaged would be brought in alongside TDM schemes (such as greater use of TravelSmart programs) and other options in the aggregate package (such as urban re-design and road pricing) that should provide enough incentives/signals to limit such rebound behaviours.

TDM marketing activities (e.g. individualised information and encouragement programs for trip planning and sustainable transport use) have often been found to be relatively cost-effective means of lowering average per capita VKT. Studies cited by VTPI (2011, http://www.vtpi.org/tdm/tdm23.htm) observe that such marketing can reduce automobile use by 5-15 per cent across a targeted population group (and can also increase the effectiveness of allied transport demand management/reduction strategies). For example, an assessment of part of the Queensland TravelSmart program (see Socialdata Australia 2007, *Brisbane TravelSmart Final Report, Brisbane North TravelSmart Communities, TravelSmart Individualised Marketing Brisbane North*) observes that the 'results from the evaluation showed a 13 per cent reduction in car as driver trips'.

Actual long-term impacts across the whole community will typically be a subset of such reductions, limited partially by how complete a coverage (of the city-wide population) the TDM/telecommuting measures attain, what proportion of the total population take up either the offer of the individualised 'social marketing' or any opportunities for flexible work practices, and whether some of the TDM-targeted individuals eventually revert to previous travel behaviours. Calculations for this particular option assessment also have to take into account that VKT reductions stated from TravelSmart studies will often consist of both trip reduction and mode changing (and here we are only evaluating the total trip reduction component). Also the base case will already include some abatement from such activities (since not only is telecommuting becoming more accepted, but many TravelSmart programs are already in place – with the base case projections already allowing for around half a megatonne abatement per annum from TDM initiatives like the previous National Travel Behaviour Change Project).

For this particular assessment scenario, the TDM measures are assumed to support an eventual city-wide adoption fraction of 0.1 (for either telecommuting or major household re-arrangement of vehicle travel patterns, though this is quite speculative – and where large-scale adoption of major commuting reductions could require changes to standard workplace/employment practices), and where each person who adopts telecommuting is assumed to achieve the proportional daily VKT reduction of the Brisbane pilot study (Marinelli et al. 2010). The TDM measures will not typically target public transit reductions, and a lower adoption fraction has been chosen for possible telecommuting impacts on Urban Public Transport (UPT) demand.

Possible 2050 abatement is then roughly estimated at about 1.3 Mt per annum (for the individual option); or about 0.2 Mt per annum for the current scenario's contribution to the aggregate abatement (i.e. if this option is evaluated with all the previous options having reduced average urban transport emission levels).

Mode shift: Urban car to public transport

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Urban vehicle use	Mode shift car-UPT	0.15	Urban light vehs	43.7	0.59	3.9
'In sequence' calculated contribution to aggregate abatement						
Urban vehicle use	Mode shift car-UPT	0.15	Urban light vehs	7.6	0.46	0.5

Urban public transport (UPT) offers significant energy savings over private car travel (e.g. see Figure 21.3 of the Garnaut Report, http://www.garnautreview.org.au/pdf/Garnaut_Chapter21.pdf). At loading levels averaged over the whole day (peak and off-peak) and all travel, car travel currently emits about 210 grams of total FFC CO_2 equivalent per passenger-kilometre (for all gases, both direct and indirect, and including both upstream and tailpipe emissions), bus travel about 90 gCO_2e/pkm and passenger rail travel about 110 gCO_2e /pkm.

These average modal intensities are estimated as being performed at an average occupancy factor of about 1.6 (persons per vehicle, averaged over all travel) for cars and 10 for buses; with the value for rail being increased by low average loading levels during off-peak periods and high relative emissions due to present-day electricity production – so is not fully reflective of rail's relative energy efficiency. For average urban commuting (or typical Australian city peak period travel) the values are higher at 310 grams of total CO_2e equivalent per passenger-kilometre (all gases) for the current car fleet – with a lower average operating occupancy level of about 1.1-1.2 persons per car; and between 40-50 gCO_2 /pkm for bus and rail travel (which typically have 80 per cent or above loading levels during the peak). That is, even under the current fuel mix for electricity generation (predominantly coal powered), UPT has on average between a half to a sixth of the emissions (on a full fuel cycle basis, per passenger-kilometre) of car travel.

However, given the dominance of present-day car travel (where close to 90 per cent of current urban passenger-kilometres are performed by light motor vehicles and only about 10 per cent by rail, bus and ferry), any mode shift capable of significantly affecting the urban car emission total will probably involve substantial expansions to UPT patronage levels.

The last few years have seen substantial rises in passenger numbers across many Australian public transit systems, partially due to periods of higher than average fuel prices and to various infrastructure expansions (see Cosgrove 2011 for detailed time-series). Following on from such trends, the base case projections already incorporate UPT increases of approximately a doubling of current travel volumes by 2050 (not only from future increases to daily travel and urban population levels, but also from some modal shift encouraged by factors such as increasing traffic congestion and rising oil prices)[7].

The scenario assessed here assumes that this base case doubling could be increased substantially (almost doubling again) through some package of transit assistance/encouragement measures – though the 15 per cent of car travel shifted to UPT by this scenario would require expansion of transit service levels (with

[7] Note that for more detailed descriptions of such elements of the base case projections (for transport demand, energy use and emissions levels) than are provided in this report's summary section on the 'Base Case emission trends', see *Long-term Projections of Australian Transport Emissions: Base Case 2010* (BITRE 2010): http://www.climatechange.gov.au/publications/projections/~/media/publications/projections/bitre-transport-modelling-pdf.pdf.

repercussions on rolling stock and infrastructure adequacy) to accommodate these large increases in total UPT patronage by 2050. Part of enabling these substantial changes to UPT patronage trends could be other options assessed as part of the complete package: including urban transit-oriented design, providing price signals to motorists (such as road/congestion pricing and increased parking charges), and UPT encouragement (including TDM marketing and improved traveller information systems).

Average daily operating emission rates (per pkm) for each mode are assumed – where car fuel efficiency increases over time in the projections, as does the emission performance of UPT (especially that of electric rail, where under the 'core policy' setting for power generation mix in Treasury's recent modelling studies, increasing renewable generation substantially decreases the emission rate of Australian electricity provision over the coming decades). For details of the Treasury modelling/scenarios see *Strong growth, low pollution: modelling a carbon price* (Commonwealth of Australia 2011a) – http://www.treasury.gov.au/carbonpricemodelling/content/default.asp.

The calculations in this scenario use assumptions that approximately a third of the extra patronage (generated by the mode shift measure) can be accommodated by base case UPT service levels, with the remainder requiring further service provision (e.g. putting on more buses). Under these assumptions, modal shift from car to UPT is estimated as having net 2050 abatement potential of about 4 Mt per annum (FFC direct CO_2 equivalent) when considered as an individual option. Since by this stage in the aggregation process, car travel has become highly emission-efficient and the residual market small, the contribution to the aggregate sequence abatement is only about 0.5 Mt per annum (for 2050).

Higher abatement levels would be attainable under more radically increased UPT service/infrastructure scenarios, but could involve high implementation costs.

There is not really any lack of knowledge concerning the energy advantages of UPT – the main uncertainties relate to:

- properly assessing both the likely and maximum possible scope for increases in future transit patronage levels – especially given the various capacity constraints (e.g. with some peak services already becoming overcrowded)
- the proportion of car drivers who can be successfully encouraged to change modes, and the best ways of promoting that shift.

Some of the main challenges to radically increasing UPT mode share would probably revolve around infrastructure and rolling stock adequacy issues (especially considering the large numbers of passenger trips potentially changing modes), improving operations/services and problems convincing enough drivers to reduce their car travel.

Mode shift: Urban car to non-motorised transport

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Urban vehicle use	Mode shift car-walk	0.30	Urban trips < 2km	0.8	1.00	0.2
Urban vehicle use	Mode shift car-cycle	0.20	Urban trips < 10km	7.2	1.00	1.4
'In sequence' calculated contribution to aggregate abatement						
Urban vehicle use	Mode shift car-walk	0.40	Urban trips < 2km	0.3	1.00	0.12
Urban vehicle use	Mode shift car-cycle	0.25	Urban trips < 10km	1.3	1.00	0.3

This next joint option in the Urban Transport category contemplates the potential for shifting the shorter urban trips currently done in cars to non-motorised transport such as walking and cycling.

Firstly, the option considers shifting short trips currently done in cars to walking. The calculations in the assessment table use statistics on average daily travel from Sydney's annual Household Travel Survey (for summary reports see the NSW Bureau of Transport Statistics website: http://www.bts.nsw.gov.au/ArticleDocuments/79/2008_09_HTS_Summary_Report.pdf.aspx?Embed=Y), and assumes average results from this survey are representative of Australian urban travel patterns – where a typical Sydney car driver is found to take 3-4 trips per day, on average, with a mean trip distance of about 9-10 km. The spread of the surveyed average distance recordings (e.g. see Figure 3.15 of the referenced summary report) has car trips following a roughly normal distribution, peaking about 5 km per trip. This distribution implies that close to 10 per cent of urban car trips are typically below 1 km (which comprises slightly below 1 per cent of urban car pkm, and with around 3 per cent of pkm accounted for by trips below 2 km).

This assessment assumes that approximately 1.5 per cent of car travel can be suitably targeted for switching to walking trips. The 'market emission' estimate in the top line of the above table relates to the projected amount due to 1.5 per cent of base case urban car use (where it has been assumed that short car trips have worse fuel efficiency than average).

For the 'in sequence' case, the residual market emissions have been reduced by the options higher in the aggregation listing, but the size of the market has also been increased for this particular assessment, with the analysis including a co-location enhancement factor, due to the action of the previous option on urban design and land-use change. As discussed by the Victoria Transport Policy Institute (VTPI 2011, http://www.vtpi.org/tdm/tdm38.htm) in the context of achieving 'Smart Growth' land management:

> 'Residents of more walkable communities typically walk 2-4 times as much and drive 5-15 per cent less than if they lived in more automobile-dependent communities.'

For this scenario it is assumed that the maximum amount of short car trips that could be successfully replaced by walking is about 30 per cent (relative to base case trends) for the stand-alone case, and somewhat higher at about 40 per cent for the more-connected, more-pedestrian-friendly cities presumed to result from the Aggregate Scenario (and the inherent elements of urban re-design and road pricing). These assumed proportions are quite speculative, and actual mode shifts obtained will depend crucially on factors such as how much of this short-distance car travel involves load-carrying or serving passengers, and developing community attitudes to non-motorised transport.

Under the scenario assumptions, 2050 abatement potential for greater walking participation comes to approximately 0.2 Mt per annum ('individual' abatement). For the 'in sequence' calculation, the emission reduction estimate comes to about 0.1 Mt per annum (for 2050).

Secondly, as well as considering the potential for shifting car trips shorter than a kilometre or so to walking, the prospect of shifting some short to medium length car trips to cycling is added. Almost 15 per cent of urban car pkm is typically due to trips less than 5 km in length, and trips of less than 10 km account for close to a third of all urban car travel (again see data from the Household Travel Survey, http://www.bts.nsw.gov.au/ArticleDocuments/79/2008_09_HTS_Summary_Report.pdf.aspx?Embed=Y). On the basis of these proportions, it is here assumed that around 15-20 per cent of car travel can be suitably targeted for switching to cycling.

The market emission estimate in the top half of the assessment table (second row of estimates) relates to the CO_2e output due to around 15 per cent of projected (2050 base case) urban car use (where it has again been assumed that short car trips have worse fuel efficiency than average). For the lower half of the table (bottom row of estimates) the residual market emissions have again been increased for this assessment (similarly to the walking case), with the values also incorporating a co-location enhancement factor (due to the modal effects of the previous option on urban design).

For this scenario it is assumed that the maximum amount of these shorter car trips that could successfully be shifted to cycling is about 20 per cent for the base case, or about 25 per cent for the 'in sequence' estimates (flowing from the enhancements to cycling infrastructure intrinsic to the urban design elements of the Aggregate Scenario – though with the assumed proportions again quite speculative, and still depending crucially on factors such as load-carrying capability and public perceptions of cycling).

Under the scenario assumptions, 2050 abatement potential for greater cycling participation comes to approximately 1.4 Mt per annum (as 'individual' abatement); and considered 'in sequence' has a contribution to the aggregation of about 0.3 Mt per annum.

Substantially higher emission savings would be possible with high enough community acceptance of non-motorised activity, especially if vehicles such as power-assisted bicycles and tricycles (which widen the scope for cycle participation) or velomobiles (which can have substantial load-carrying and weather protection capability) eventually become sufficiently popular (assuming any concerns around on-road safety can be successfully addressed). The next option section attempts some rough estimates for possible mode-switching impacts should such vehicles become more readily available/affordable in the future.

Mode shift: Urban car to velomobiles

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Urban vehicle use	Mode shift car-velomobile	0.10	Urban trips < 20km	13.8	0.95	1.3
'In sequence' calculated contribution to aggregate abatement						
Urban vehicle use	Mode shift car-velomobile	0.15	Urban trips < 20km	2.1	0.95	0.3

This last of the mode-shift options within the Urban Transport category posits the possibility of shifting future urban car trips to power-assisted cycling or velomobiles. A velomobile is essentially a cycle (of between 2-4 wheels) with a fairing, i.e. is enclosed for aerodynamic advantage and offers protection from collisions, the road surface and the elements. Such 'cycle cars' are usually (though not exclusively) single-passenger vehicles, can have substantial load-carrying and weather protection capability, and have traditionally been human-powered – though for this scenario we are more interested in the potential of power-assisted velomobiles (that will have some features in common with 'micro-cars' but be even lighter and smaller still). The history of velomobiles is examined by Frederik Van De Walle (2007) in *The Velomobile as a Vehicle for more Sustainable Transportation* (http://users.telenet.be/fietser/fotos/VM4SD-FVDWsm.pdf).

So far, velomobiles have had a limited market appeal and have often been relatively expensive (with price improvements hindered by current low volumes of sales and manufacture), but future innovations in design and fabrication should improve affordability and the model range. Some modern designs, with 3-wheel configurations for stability, integration with portable IT/telephony devices and electric pedal-assist technology (providing considerable range extension and reduced hill-climbing effort), should present an attractive alternative to short car trips for a growing proportion of urban travellers. Given the many advantages a power-assisted fully-enclosed velomobile already offers for urban travel – including greater comfort than a bicycle and improved crash resistance (though still not comparable safety features of a full automobile), low maintenance, luggage/shopping capacity, proper headlight capability for night-time travel, and smaller parking footprint than a car – their very low penetration into the urban travel market so far points to problems not only with current cost and supply levels, but also potentially with cultural acceptance. Richardson, Burns and Haylock (2011, *PUUNK my ride: development of the Personalised User-generated Upcycled N-configurable Kit velomobile*) discuss some of the issues that improving social recognition and approval of velomobiles may involve, including dealing with the current 'negative perception by the broader community that they are either a complicated bike or a lesser car'.

With power-assist batteries and drive-trains improving, and the ability of such vehicles to widen the scope for cycle participation (both to users requiring long average trip lengths or luggage space and to portions of the community not physically capable of much unassisted cycling), velomobiles should be able to account for significant future market share, if the public acceptance issues can be overcome. Power-assisted cycling technologies are, after all, becoming mainstream consumer items – with world-wide sales of electric bicycles ('E-bikes' and 'pedelecs') reaching 27 million in 2010 (largely due to the Chinese domestic market but with growing European sales – see Parker 2011, *In Europe 250 watt pedelecs reduce pollution and improve the safety and mobility of young and elderly riders*) and possibly outstripping annual global car sales within a decade or so. Another advantage of such power-assist technology is that it improves UPT access, by widening the catchment area for transit (i.e. longer trips to rail or bus stations become practical).

So, as well as considering the potential for shifting short car trips to walking and cycling, the prospect of shifting short to medium length car trips to power-assisted cycling is added here. It is assumed for this assessment scenario that a range of vehicle trips shorter than about 20 kilometres, roughly accounting for about 30 per cent of urban car travel, can be suitably targeted for switching to velomobiles or E-bikes (where the market estimate in the top half of the assessment table relates to the 2050 base case emissions due to that 30 per cent of projected urban car use, and the lower half of the table has a residual 'market emissions' estimate slightly increased from this proportional VKT level due to some urban design co-location enhancement, as was assumed for non-motorised travel in the previous option assessment).

For this particular scenario it is assumed that the maximum amount of such car trips that could successfully be shifted to such ultra-light vehicles is about 10 per cent for the base case, or about 15 per cent for the 'in sequence' estimates (the higher adoption fraction again flowing from the urban design enhancements of the Aggregate Scenario).

Under the scenario assumptions, 2050 abatement from possible take-up of power-assisted velomobiles comes to approximately 1.3 Mt per annum (as 'individual' abatement); and considered 'in sequence' has a contribution to the aggregation of about 0.3 Mt per annum.

The assumed market and adoption proportions are very speculative, given the uncertain community acceptance such vehicles will have in the future – though if public perceptions and appropriate regulation eventually favour power-assisted cycling, it could offer substantial emissions abatement potential.

Eco-driving: light vehicles

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Vehicle performance	Eco-driving	0.45	Light vehicles	68.1	0.08	2.5
'In sequence' calculated contribution to aggregate abatement						
Vehicle performance	Eco-driving	0.45	Light vehicles	12.7	0.04	0.2

Ecodriving, essentially driving as smoothly as road conditions allow, has a relatively significant emission reduction *potential*, assuming drivers adopt it. As described by Smit, Rose and Symmons (2010, *Assessing the Impacts of Ecodriving on Fuel Consumption and Emissions for the Australian Situation*):

> 'At its core, ecodriving involves monitoring engine revolutions (or revs) to make timely gear changes, travelling at an optimum speed, and anticipating traffic conditions in order to maximally conserve momentum. Thus ecodriving emphasises a smooth driving style. Drivers are encouraged to "flow" the vehicle, anticipating potential interactions by looking further down the traffic stream so they can brake less forcefully and less often and avoiding unnecessary acceleration. Other elements of ecodriving include using the air conditioner sparingly, minimising idling, optimising aerodynamic profile, minimising unnecessary weight, adhering to a regular servicing regime, and ensuring tyres are inflated to their maximum advisory pressures.'

For car traffic, vehicle testing typically finds around a 40 to 45 per cent variance in the rate of fuel consumption between the best performing drivers and the worst – e.g. see EPA Victoria (2007), *How you can save on fuel costs*, http://www.epa.vic.gov.au/air/savefuel/savefuel.asp; http://en.wikipedia.org/wiki/Fuel_efficient_driving; Haworth N and Symmons M. (2001), *The relationship between fuel economy and safety outcomes*, http://www.monash.edu.au/muarc/reports/muarc188.pdf – and where the current driving population will contain a range of different performers, covering the span between 'optimal' and 'poor' on-road practices. Urban driving will typically be more strongly affected by such differences, but all driving conditions offer some scope for fuel reduction benefits from various eco-driving principles.

Estimates for fleet-wide effects of eco-driving (including appropriate encouragement/training schemes), across the international literature, typically find fuel reductions in the order of 3-15 per cent as feasible – with significant variation from vehicle to vehicle – e.g. see TNO (2006), *The Effects of a Range of Measures to Reduce the Tail Pipe Emissions and/or the Fuel Consumption of Modern Passenger Cars on Petrol and Diesel; and Austrian Energy Agency (2010), Ecodriving – Widespread Implementation for Learner Drivers and Licensed Drivers* (ECOWILL project website, http://www.ecodrive.org/).

Some assessment of possible Australian impacts (allowing for the differing fleet composition locally) suggest fleet-wide fuel reduction benefits are more likely to fall towards the bottom of this range (e.g. Smit, Rose and Symmons 2010, pg. 11).

There is also some concern that the effects of such programs might not be fully durable – with the possibility of some motorists trained in eco-driving techniques eventually reverting to pre-existing driving styles over time (e.g. the ECOWILL project states that 'ECO-DRIVING trainings lead to consumption reduction up to 20 per cent directly after training and about 5 per cent in the long run', http://www.ecodrive.org/en/what_is_ecodriving-/benefits_of_ecodriving/). However, this effect can be balanced somewhat by the increasing penetration of technology such as real-time fuel monitoring and in-dash feedback on driving efficiency – e.g. Klunder et al. (2009) assess that eco-driving with appropriate information and communication technology assistance offers considerable efficiency gains, with 'Eco-driver Assistance' (eco-driving aided by in-vehicle energy-use indicators and gear-shift timing advice) and 'Eco-driver Coaching' (routing advice aided by enhanced real-time traffic/map data) estimated to have a fleet-wide CO_2 reduction potential of about 10-15 per cent.

For this option, it is roughly assumed that the likely abatement, relative to the base case, lies approximately in the middle of this canvassed value range for possible fleet effects (i.e. between about 3-15 per cent reduction in average fuel consumption, with the lower end of the range typically from standard eco-driving techniques and the upper end from IT-assisted eco-driving) – setting an assumed saving fraction for the upper assessment row of 0.08 (for widespread adoption of programs encouraging a movement to optimal driving practices).

The overall emission saving fraction assumed for light vehicles has to allow for the likely greater adoption of technological improvements in the future (e.g. better engine management systems) that could reduce the potential for fuel savings by individual behaviour changes. As stated by Smit, Rose and Symmons (2010), consideration has to be made of:

> 'future changes in the fleet composition with respect to vehicle and engine technology. Apart from an expected further diversification of personal mobility options reflecting increased use of innovative vehicle designs, including non-motorised and motor-assisted vehicles (Rose and Richardson, 2009), motor vehicles are expected to be further optimised for fuel efficiency, which would include (further uptake of) e.g. hybridisation, engine downsizing, variable valve timing and direct injection petrol engines. It is generally assumed that future vehicles will have less potential to reduce fuel consumption by adaptation of driving style because of their already optimised fuel efficiency.'

For the upper part of the assessment table (the 'individual' abatement calculations), the market emissions is taken to be the 2050 base case level for non-electric light vehicles. For the lower part of the assessment table (the 'in sequence' calculations), the estimated 'savings fraction' has been reduced to allow for the high proportion of electric vehicles and plug-in hybrids (and other vehicles using technologies such as regenerative braking) in the Aggregate Scenario, resulting in an estimated savings fraction for this aggregation step of about 0.04.

It has also been assumed that roughly half of light vehicle users adopt the proposed driving practices (versus an assumed 5 per cent implementation of such eco-driving programs in the base case – leading to a net adoption fraction of 0.45), resulting in 2050 abatement of about 2.5 Mt per annum (considered as an individual measure), or about 0.2 Mt per annum as this step's contribution to the aggregate process (considered 'in sequence').

This option would not tend to exhibit the same amount of lags as measures requiring major technology change, and the resulting slow diffusion through the vehicle fleet (even though greater penetration of certain technological innovations, such as dashboard feedback on instantaneous and average fuel performance, aiding this option, will have some of these lagged fleet effects).

One possible concern with some eco-driving techniques is a measured increase in vehicle NO_x emissions (Smit, Rose and Symmons 2010), though with these particular future scenarios that will probably be minimal, since even in the base case projections, emission control improvements by 2050 have reduced expected fleet emissions of pollutants such as NO_x to relatively low levels..

There is not generally a lack of knowledge concerning eco-driving's benefits and how to structure appropriate training campaigns for targeted groups of motorists – some of the main uncertainties would relate to:

- the amount of current road-users across the full fleet exhibiting highly fuel-inefficient practices and what proportion of these drivers can be successfully encouraged to change their driving practices
- the extent technological improvements to vehicles and road management systems will reduce this variation in fuel consumption due purely to driver behaviour.

Thus the main barriers/challenges to successful implementation are likely to be communicating the benefits of eco-driving to drivers and getting their acceptance of the driving practices involved.

5. INFRASTRUCTURE

This abatement category, *Infrastructure*, has been subdivided into two main types – 'Hard' infrastructure (generally involving physical changes to the built environment or its energy inputs) and 'Soft' infrastructure (primarily involving changes to Information and Communication Technology systems or their operation).

Pavement design

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
'Hard' infrastructure	Pavement design	0.20	Road construction	3.0	0.30	0.18
'In sequence' calculated contribution to aggregate abatement						
'Hard' infrastructure	Pavement design	0.20	Road construction	2.5	0.30	0.15

Emission benefits can be achieved by changing the design of pavements applied for road construction. If a pavement is designed to last longer, and therefore require less frequent replacement, and/or to incorporate materials requiring less energy to produce, then annual emissions generated by their overall materials production will be decreased.

Materials volumes for different design-level roads – e.g. standard, highway, long lasting or long lasting polymer modified binders (PMB) premium – are dependent on the thickness of the asphalt and aggregate[8], and design life. For example design standards for highway construction have five times the amount of asphalt compared to an urban road (250 mm of asphalt compared to 50 mm). Further moving to a longer lasting design requires eight times the amount of asphalt (400 mm). Specifically, for the standard design, the aggregate thickness is assumed to be 200 mm, with asphalt at 50 mm thickness, over a design life of 20 years; and for the highway design, the aggregate thickness has been increased to 450 mm and asphalt to 250 mm (where the production of aggregates produces considerably less greenhouse gas emissions per tonne of material, compared to asphalt).

Changes from a standard design to a long lasting design can be achieved by using a design that has a disposable surfacing but the remainder of the pavement lasts considerably longer – involving a higher initial cost. Under such a change, the granular pavement is substantially replaced with asphalt, which leads to a significant increase in emissions for the production of the initial road materials (i.e. used during construction). Yet since the pavement needs replacement much less often – changing from 20 years in the conventional design to 60 years in the long lasting design – total emissions over the road's design lifetime are substantially reduced. Annualised emissions (over the 60 years of such pavement life) due to the energy use from production of the road's construction materials are predicted to be almost halved by using these longer lasting designs.

Based on ARRB estimates of typical tonnes of material required per lane-kilometre for the various road designs (including adjustments for different road thickness and design life), and characteristic CO_2 emission rates from energy use during the production of each major material, BITRE estimates (using data on Australian aggregate road lengths, projected population increases, and ARRB assumptions concerning likely future trends in average road construction practices) that 2050 baseline emissions from the annual materials production required for national road construction could lie between about 2-3 Mt of CO_2 equivalent[9].

[8] Where 'aggregate' is a broad category of coarse particulate material used in construction, including sand, gravel or crushed stone.

[9] Note that these 'infrastructure' emissions due to pavements are extra to the transport sector emissions dealt with in the base case projections (for fuel use by Australian domestic transport operation) – as provided in BITRE (2010) and summarised in this report's section on 'Base case emission trends'. That is, such emissions are not included in the values provided in Table 5 – however, these extra emissions are added into some sectoral totals provided in Tables 6 and 7.

An approximate 2050 'market emissions' value of 3 Mt CO_2e has been chosen for the 'individual' option assessment (with a somewhat lower value input for the Aggregate Scenario calculations, under the assumption that the infrastructure outcomes of the *Urban design* step, in the option sequence, reduce overall road construction/maintenance activity). These assumptions lead to rough estimates for possible reductions in such average (annualised) emissions (from energy use during the production of materials for major road rehabilitation/construction) – by using a range of improved longer-lasting pavement designs and construction materials on suitable roads – in the order of about 0.2 Mt by 2050.

The knowledge base in assessing such infrastructure design issues reflects a need for further research to determine the full greenhouse gas benefits of the various pavement options, and other means of optimising road asset use, especially with regards to relative road performance characteristics.

Pavement smoothing

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
'Hard' infrastructure	Pavement smoothings	0.80	All road vehicles	111.7	0.03	2.7
'In sequence' calculated contribution to aggregate abatement						
'Hard' infrastructure	Pavement smoothings	0.80	All road vehicles	26.5	0.03	0.64

Emission benefits can also be achieved by optimising the surface characteristics when applying or re-applying road pavement materials. This next 'infrastructure' step in the aggregation estimation procedure adopted in this report considers re-surfacing Australia's main roads to a smoother average standard. There should be no safety reduction implications from such a measure, since there is typically no direct correlation between road smoothness – i.e. amount of average roughness measured in IRI (International Roughness Index) or NAASRA Roughness Meter (NRM) – and skid resistance. Skid resistance is typically a function of micro and macro texture – quite different to measured 'smoothness'. This measure of smoothness relates to vehicle ride quality and is not based on the tyre-pavement contact interface, but rather is based on the profile of the pavement. It remains essential however, that reductions in roughness are not achieved by pavement treatments which reduce skid resistance.

The estimates presented for this option are based on the results of BTCE Working Paper 32 (*Roads, Vehicle Performance and Greenhouse: Costs and Emission Benefits of Smoother Highways*, BTCE 1997) and the results of Chapter 16 in BTCE Report 94 (Transport and Greenhouse: Costs and options for reducing emissions, BTCE 1996b), which judges that:

> 'Decreasing the roughness of roads can reduce greenhouse gas emissions without curtailing travel. An acceptable level of road roughness is 110 NRM (a measure of roughness). Resurfacing the National Highway System (NHS) to a roughness of 100 NRM (a smoother road system) would reduce road transport emissions by about 0.7 million tonnes of CO_2 equivalent by 2015...
> Motorists would save about $650 million from fuel and vehicle maintenance, but government expenditure of $699 million would be required...
>
> Relative to a basecase of 110 NRM, resurfacing to a roughness of 90 NRM would result in a reduction in CO_2 equivalent emissions of 1.3 million tonnes by 2015... Resurfacing to a roughness of 60 NRM would generate a reduction in emissions of 3.8 million tonnes by 2015...'

Under the scenario inputs – including the assumption that the new standard would eventually apply to the full road system, but that around 20 per cent of roads would already have suitable smoothness in the base case (resulting in a net adoption fraction of 0.8), and an estimated savings fraction of about 3 per cent derived from the BTCE (1996b, 1997) reports results – 2050 abatement potential is approximately estimated as about 2.7 Mt CO_2e per annum (for the 'individual' option abatement); and with an 'in sequence' contribution to the sector aggregate of about 0.6 Mt per annum.

The MIRIAM project being pursued in Europe and the USA addresses this issue. Extension and adaptation of MIRIAM methods has the potential to improve road smoothing initiatives in Australia (see http://miriam-CO2.net).

Pavement materials

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
'Hard' infrastructure	Pavement materials	1.00	Road resurfacing	1.0	0.11	0.11
'In sequence' calculated contribution to aggregate abatement						
'Hard' infrastructure	Pavement materials	1.00	Road resurfacing	0.7	0.11	0.08

This next Infrastructure component considers the possibility of using alternative road materials and less energy intensive practices to deliver infrastructure services at current or improved levels of service. Some of the alternatives to the most common road materials – such as dense graded asphalt used for urban roads (50 mm hot mix asphalt, typical density of 2.4 t/m^3 and here assumed to average lane width of 3.7 m) – include emulsion asphalt, polymer modified asphalt , recycled asphalt, and warm mix asphalt (for urban road re-surfacing). Also, geo-polymer concrete can be compared against a base case for standard concrete (at 175 mm thick, typical density of 2.4 t/m^3 and 3.7 m wide lanes).

The embodied energy in warm mix asphalt (WMA) is predicted to be the same as hot mix asphalt, assuming that the warm mix process uses water as the agent rather than a proprietary agent. If a proprietary agent was used then the embodied energy of WMA would be higher than comparable hot mix asphalt. The overall emission reductions come from production energy savings due to less applied heat (and thus less heating fuel use). For projection purposes, a 5 per cent energy improvement in production processes is assumed to occur over every 10 years. This is based on asphalt plants modernising and a switch to more carbon-efficient fuels.

Whilst there are some advantages in using concrete in the construction of road infrastructure, whereby it does not depend directly on the price of oil compared to bitumen, concrete production is a heavy greenhouse gas emitter. Research indicates that emissions of CO_2 and NO_x are significantly higher for concrete (Portland cement) than for asphalt. Geo-polymer concrete uses fly ash, which is produced as a by-product from coal-fired power stations. The production of geo-polymer concrete produces less greenhouse gas emissions than Portland cement (Austroads, 2010a).

The estimates for this scenario assume that 50 per cent of maintenance is carried out using asphalt as this was used as a comparison against the alternative materials listed above. Whilst the other 50 per cent of maintenance was broadly estimated to be conducted using sprayed seals, and for the purpose

[10] Note that these 'infrastructure' emissions due to pavements are extra to the transport sector emissions dealt with in the base case projections (for fuel use by Australian domestic transport operation) – as provided in BITRE (2010) and summarised in this report's section on 'Base case emission trends'. That is, such emissions are not included in the values provided in Table 5 – however, these extra emissions are added into some sectoral totals provided in Tables 6 and 7.

of the calculations only asphalt was considered as it was assumed that there would be little technology improvements to reduce CO_2 emissions for sprayed seals in the future.

Based on ARRB estimates of typical tonnes of material required per lane-kilometre for various road pavements, and characteristic CO_2 emission rates from energy use during the production of each major material (e.g. resulting in an estimate for production emissions of about 26 tonnes of CO_2 equivalent for each lane-km of standard asphalt applied), BITRE estimates (using data on Australian aggregate road lengths, and projected population increases), that 2050 baseline emissions from the annual materials production required for national asphalt resurfacing could lie between about 0.5-1 Mt of CO_2 equivalent[10].

An approximate 2050 'market emissions' value of 1 Mt has been chosen for the 'individual' option assessment (with a somewhat lower value input for the Aggregate Scenario calculations, under the assumption that the infrastructure outcomes of the Urban design step, in the option sequence, reduce overall road construction/maintenance activity). These assumptions lead to rough estimates for possible reductions in such average emissions from energy use during the production of materials for asphalt road maintenance, by using a range of improved materials/surfaces (based on ARRB assumptions concerning potential proportions of alternative materials applied in road maintenance) in the order of about 0.1 Mt by 2050.

Note that in whole life-cycle terms, greenhouse gas emissions associated with road construction and maintenance are relatively small (less than 5 per cent) when compared with total vehicle operation emissions (as discussed earlier in the report) (EAPA & Eurobitume (2004, pg.9).

Some possible areas for future consideration include further energy savings from the use of solar road surfaces, kinetic vibration and micro wind-turbines in road construction.

Airspace management

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
'Soft' infrastructure	Airspace management	1.00	Domestic aviation	17.4	0.10	1.7
'In sequence' calculated contribution to aggregate abatement						
'Soft' infrastructure	Airspace management	1.00	Domestic aviation	6.0	0.10	0.6

The aviation options reviewed by the previously referenced Pew Center report also includes improvements to the sector's operational practices (http://www.pewclimate.org/docUploads/aviation-and-marine-report-2009.pdf, *Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies,* McCollum, Gould & Greene 2009), finding (see http://www.pewclimate.org/technology/factsheet/Aviation):

> 'A number of strategies can mitigate the rising level of GHG emissions from the aviation sector. In the near term, adopting navigation systems and air traffic control techniques that minimize fuel use and idling can reduce emissions by as much as 5 per cent...
> Optimizing flight paths and reducing airport congestion could immediately reduce the aviation sector's GHG emissions. Adopting advanced communication, navigation, and surveillance and air traffic management (CNS/ATM) systems can reduce the time aircraft spend idling on runways or circling airports waiting to land, thus reducing fuel use and associated emissions...'

The scenario estimated here assumes that an approximate 5 per cent improvement in aviation sector fuel efficiency included in the base case projections – from already planned air traffic management (ATM) reforms – could be lifted to something like an extra 10 per cent improvement, by further optimising ATM practices (and thus facilitating improvements to airline industry logistics). The resulting estimate for 2050 abatement, across the civil domestic aviation sector, is around 0.6 Mt per annum for the option considered as part of the aggregation sequence, or about 1.7 Mt per annum when considered as an individual option.

Traffic management

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
'Soft' infrastructure	Traffic management	0.50	All urban vehicles	59.9	0.10	3.0
'In sequence' calculated contribution to aggregate abatement						
'Soft' infrastructure	Traffic management	0.50	All urban vehicles	10.6	0.10	0.53

Traffic can be managed through a variety of schemes – some currently implemented and some already planned for future congestion control. This option envisages the greater (than BAU) use of some proposed road and traffic management technologies, along with the possible introduction of some novel techniques over the longer term.

A trial of proposed coordinated ramp signals undertaken over 15 kilometres by Vicroads (conducted in 2008) resulted in a 4.9 per cent increase in average flow (passenger car units/hour/lane), 34.9 per cent increase in travel speed (from 48.9 to 66 km/h) and 65.3 per cent reduction in delay (in terms of min/km) – see http://transport-futures.com/2010/11/smart-motorway-management-what-is-happening-with-traffic-in-australia/.

Managed motorways (e.g. see http://www.budget.gov.au/2011-12/content/ministerial_statements/urban/html/ms_urban-02.htm) can include:

- variable message signs, which can deliver an 8 to 13 per cent increase in travel speed
- ramp metering, capable of delivering a 13 to 26 per cent increase in travel speed

If average speeds are lower than optimal (in engine efficiency terms), such as during congested traffic streams, increases in average travel speeds will tend to improve fuel efficiency and thus reduce net CO_2 emissions. If average speeds improve by the order of 15 per cent on a typical metropolitan road, then concurrent improvements, normally in the order of 5 per cent, can be expected in average fuel efficiency across that traffic stream (based on generally observed/modelled relationships between average link speeds and average fuel consumption). Meanwhile, since optimal travel speeds (again from a fuel efficiency point of view) tend to often lie around 80 km/h, vehicles travelling at high speeds can increase CO_2 emissions from road use – e.g. an assessment by Smit & Broom (2009, *Development of a new high resolution traffic emissions and fuel consumption model for Australia and New Zealand- Model Application*) found that control of high speeds on freeways could potentially reduce total traffic stream CO_2 emissions by around 7 per cent.

Klunder et al. (2009), *Impact of Information and Communication Technologies on Energy Efficiency in Road Transport*, reviews a variety of promising measures that offer potential CO_2 reduction through traffic control; some of which include: enabling platooning (the synchronised movement of two or more vehicles, reducing aerodynamic drag), traffic signal optimisation (such as 'Dynamic traffic light synchronisation' relying on real-time data on traffic conditions to optimise journey times and lessen delays), fuel-efficient route choice navigation (again relying on dynamic real-time information about congestion and traffic incidents across the road network), advanced trip scheduling (using current and predicted traffic conditions to further minimise delays), Slot management/allocation (typically applied to heavy vehicles, where the use of the existing road capacity is improved by vehicle fleet owners reserving 'slots' in advance, and then only heavy vehicles that have booked a slot are allowed to enter the highway during the controlled times). Each measure typically had abatement potential estimated at a few per cent; with the order of 10-15 per cent aggregate CO_2 reductions hypothetically possible from the whole set of measures assessed if their abatement effects are roughly additive.

Dinica V, (2002, *Energy Policies for CO_2 Emission Reduction,* Center for Clean Technology and Environment Policy) also considers traffic management improvement as having the potential to reduce energy use by around 10 per cent.

For this scenario, it is assumed that appropriate infrastructure enhancements and operational improvements to traffic control systems are implemented in the future to reduce the average fuel intensity of urban traffic streams by about 10-15 per cent (where a savings fraction at the low end of this range has been chosen to allow for the likelihood that several such innovations will be introduced even under business-as-usual conditions, and so already form part of the base case). This savings assumption is probably a conservative one (especially given that the adoption fraction does not apply these practices to the full road network, but assumes that they will be practical over approximately half of urban road systems), and higher abatement values could be feasible. The resulting estimate for 2050 abatement is around 3 Mt per annum (considered as an individual option), and with an aggregate abatement contribution (when considered 'in sequence') of about 0.5 Mt.

UPT priority and information provision

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
'Soft' infrastructure	UPT priority + info	0.50	UPT	2.5	0.10	0.12
'In sequence' calculated contribution to aggregate abatement						
'Soft' infrastructure	UPT priority + info	0.50	UPT	1.4	0.10	0.07

UPT priority signalling and the further provision of UPT information systems are roughly estimated to lead to a savings fraction in the order of 10 per cent.

For some discussion of related issues, see the 'Travel planning' section of *Low Carbon Scotland: Meeting the Emissions Reduction Targets 2010-2022: The report on proposals and policies*, http://www.scotland.gov.uk/Publications/2011/03/21114235/9. As well, as discussed by Transport Canada (http://www.tc.gc.ca/eng/programs/environment-utsp-puttingbusesfirst-996.htm):

> 'In Ottawa, rapid transit carries 60 to 70 per cent of transit passenger trips but uses only 20 per cent of the system's operating resources (vehicles and drivers). Surface transit routes, which provide neighbourhood access and "feed" the rapid transit system, carry the remaining 30 to 40 per cent of trips but use 80 per cent of operating resources. There is great potential to conserve capital and operating resources by improving surface route efficiency through transit priority measures.
>
> At peak periods, major bus routes without transit priority suffer a 20 to 40 per cent rate of unproductive time (e.g. at red lights, queues, merges or scheduled time points). The problem is worsened by variability in delay from one trip to the next. Transit schedules must be designed for

> the "slowest common denominator", and buses going faster than expected must eventually sit idle just to stay on schedule. This causes frustration for passengers and wastes precious dollars.
>
> Transit priority can reduce unproductive time from the 20 to 40 per cent level, bringing it as low as 5 to 15 per cent. It can also reduce the variation in delay from one run to the next. This productivity boost can enable higher levels of service or lower operating costs, while improving schedule adherence and keeping passengers happy...
>
> By reducing travel times and improving service reliability, transit priority measures make transit more competitive compared to automobile travel. Ultimately, they can help increase ridership, lower fuel consumption and emissions, and save money).'

The assumed 10 per cent improvement in average UPT efficiency (from smoother operation and improved loading patterns), with assumed adoption fraction set to half of system-wide operation, leads to an estimated 2050 abatement of around 0.1 Mt per annum (where larger net reductions are possible if significant mode share changes to UPT can be encouraged by the improved traveller information systems and reduced transit travel times).

6. FREIGHT

Mode shift: road freight to rail and sea

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Freight efficiency	Mode shift road-rail	0.40	Intercapital-trucks	14.7	0.68	4.0
Freight efficiency	Mode shift road/rail sea	0.12	Interstate rail/trucks	11.9	0.76	1.1
'In sequence' calculated contribution to aggregate abatement						
Freight efficiency	Mode shift road-rail	0.40	Intercapital-trucks	5.1	0.58	1.2
Freight efficiency	Mode shift road/rail sea	0.11	Interstate rail/trucks	4.5	0.79	0.4

This part of the aggregation scenario assumes that a substantial portion of long-distance road freight is shifted jointly onto rail and coastal shipping (specifically, resulting in 50 per cent of interstate tonne-kilometres projected to be performed by road transport in the base case, getting moved to rail and sea transport, using a roughly 80:20 split for the respective alternative modes).

This amount of mode shift, given the average energy efficiency advantages modelled for future railway and shipping operations over long-distance road freight vehicles (as projected from current trends, out to 2050, in the base case scenario) results in an estimate for net 2050 abatement of around 5.1 Mt for this joint option implementation (for the stand-alone calculations). When these modal shifts are considered 'in sequence' (i.e. evaluated after allowing for all the previous steps of the Aggregate Scenario, improving the resulting emission efficiency of each of the modes by separate amounts) a net contribution to total sectoral abatement by 2050 of about 1.6 Mt per annum results.

(For some background data on average transport energy efficiencies, per unit task, see: CSIRO (2008), *Modelling the future of transport fuels in Australia*, http://www.csiro.au/resources/Fuel-For-Thought-Modelling.html and BITRE (2010), Long-term Projections of Australian Transport Emissions: Base Case 2010, http://www.climatechange.gov.au/publications/projections/~/media/publications/projections/bitre-transport-modelling-pdf.pdf.)

Improved freight logistics

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Freight efficiency	Improved logistics	0.50	Trucks / rail	37.3	0.25	4.7
'In sequence' calculated contribution to aggregate abatement						
Freight efficiency	Improved logistics	0.50	Trucks / rail	12.0	0.25	1.5

This next part of the aggregation category that focuses specifically on ***Freight Efficiency*** considers improvements to freight logistics, including the greater use of centralised logistics.

Improvements in freight logistics provide an opportunity to integrate freight and land use planning more efficiently, and thereby promote economic growth and improved urban amenity. The King Review (King 2007) notes that abatement in freight emissions can be achieved through reducing either distances travelled (measured in vehicle-km) or carbon intensity of travel (measured in gCO_2/km), suggesting that there are particular opportunities for abatement from mode shift, supply chain rationalisation and better vehicle utilisation (Committee on Climate Change, 2010).

The King Review references a case study from John Lewis, Waitrose, Boots and Tesco, where backloading vehicles can achieve 4-20 per cent vehicle-km savings through better operational practices. The review also references evidence from Boots, Musgrave-Budgens, Londis, Sainsbury's and leading supermarket chains suggesting reductions of 2.5-6 per cent in vehicle-km are achievable through inter-company collaboration.

Additionally, for 2020, a central scenario within the King Review forecasts a potential reduction in freight distance travelled by 22 per cent (through modal shift, reduced empty running and increasing average laden payloads); and a reduction in vehicle-km of up to 58 per cent for 2050 (Committee on Climate Change, 2010).

The Victorian Freight and Logistics Council (2009, *The Good Practice Source Book*) identifies potential CO_2 reductions of 20 per cent through greater two way loading and truck optimisation and 20-30 per cent reductions (associated with a 22 per cent increase in average loading capacity) expected from the use of higher productivity vehicles (and notes that further efficiencies in supply chain initiatives can be achieved by warehouse energy conservation measures). *The Good Practice Source Book* (VFLC 2009) also suggests that reductions of the number of vehicles and distance travelled can be achieved by investing in mapping and route optimisation software (to identify the most cost-effective approach to reducing carbon emissions) and the use of global positioning systems for monitoring and refining truck movements.

The Institute for Logistics and Supply Chain Management (Victoria University) in *A Scoping Framework for Logistics Cities in Victoria* (ILSCM 2009), notes that, Department of Transport Modelling indicates significant reductions in vehicle and tonne-km travelled (of the order of 5-6 per cent) can be achieved by encouraging development of a small number of major freight and logistics precincts around outer metropolitan Melbourne. This in turn translates into similar levels of reduction in fuel usage and associated greenhouse gases.

Assuming a range of improvements in freight logistics and operations (especially concerning the optimisation of average loading levels and reducing the amount of empty running) are adopted, this scenario assumes a savings fraction of 0.25, essentially applied to half of general freight movement, leading to an estimate for 2050 abatement potential of about 4.7 Mt per annum when evaluated as an individual measure; and 1.5 Mt per annum (considered 'in sequence' with all the previous Aggregate Scenario improvements to the average emission efficiency of freight vehicles).

This is acknowledged to be an area of increasing importance to industry as commitments to environmental sustainability are implemented (particularly through reductions in energy use).

Eco-driving: heavy vehicles

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)

Estimated 'Individual' abatement potential

Vehicle performance	Eco-driving	0.50	Heavy vehicles	38.8	0.05	1.0

'In sequence' calculated contribution to aggregate abatement

Vehicle performance	Eco-driving	0.50	Heavy vehicles	10.3	0.04	0.2

Though eco-driving has a relatively significant emission reduction potential for drivers adopting it, eco-driving gains from heavier vehicles would probably not be as proportionately rewarding as for most light vehicles – with diesel engines' higher intrinsic efficiency tending to reduce the potential fuel savings between 'best' and 'poor' driving performance to around the 10-20 per cent range.

The Victorian Freight and Logistics Council (2009, *The Good Practice Source Book*) summarises the required driving behaviour:

> 'Eco-Driving was first developed through research funded by the European Commission's Director General of Energy and Transport. It refers to a set of driving principles which have been empirically proven to reduce fuel consumption. These principles include:
>
> - changing gears at the lowest engine revolutions possible;
> - driving in the highest gear possible;
> - avoiding rapid acceleration and sudden braking;
> - keeping idle time to a minimum; and
> - scanning the road ahead to allow the vehicle to 'flow' with traffic.'

The Good Practice Source Book (VFLC 2009) identifies potential CO_2 reductions from eco-driving training of 10 per cent, noting that many major Australian companies are starting to enact eco-driving education programs. In another recent assessment (Advantage Environment 2010, *"Eco-driving" Cuts Fuel Consumption*), the Swedish haulage company Wiklunds Åkeri, having invested in eco-driving instruction for its operators, equipped its vehicles with data recorders to keep track of driving patterns, with the project cutting average fuel use by at least 4 per cent.

For this scenario, an assumed savings fraction (relative to the base case) of 0.05 is chosen (against a possible value for current programs, of around 0.1, reduced by greater adoption of technological improvements in the future and with reasonable levels of implementation of such eco-driving programs in the base case) and applied to an assumed adoption of around half the heavy vehicle fleet. This results in a 2050 abatement estimate of approximately 1 Mt when evaluated as an individual option.

For the contribution to the Aggregate Scenario, this option step (after both the 'market emissions' and the 'savings fraction' get reduced by earlier option steps, such as heavy vehicles using more technologies like regenerative braking) comes to about 0.2 Mt per annum (considered 'in sequence', by 2050).

7. OTHER

For this last category in the Aggregate Scenario, a couple of options that will serve to reduce some of the forecast growth in air travel demand are briefly examined.

Telecommuting – long distance

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)
Estimated 'Individual' abatement potential						
Aviation demand	Telecommuting	0.20	Domestic aviation	17.4	0.25	0.9
'In sequence' calculated contribution to aggregate abatement						
Aviation Demand	Telecommuting	0.20	Domestic aviation	5.4	0.25	0.3

The Victoria Transport Policy Institute (VTPI 2010, http://www.vtpi.org/tdm/tdm43.htm) describes some case studies where companies have introduced or offer telecommunications services (typically to substitute for physical travel) such as tele-conferencing or 'TelePresence' rooms. However, adequate quantification of emission benefits (from net travel reduction) due to such technology appears to be so far lacking.

According to OECD (2002, *Road Travel Demand - Meeting The Challenge*):

> 'Companies such as SONY, BT, Picture Tel and Regus suggest that teleconferencing can improve the efficiency of business practices and result in travel cost-savings. A 1998 survey identified cost savings of up to 75 per cent achieved through the use of videoconferencing in place of personal travel (Regus Business Centres, 1998). Technological advances and cost reductions are likely to stimulate the use of teleconferences and the substitution of travel-based interactions in the future...
>
> Based on analysis of existing literature and 30 case studies of companies with significant ICT adoption, one-quarter of the companies surveyed reported that the substitution effects were so large that their entire business travel volume had been reduced through extensive use of telematics (Rangosch, 2000). In the absence of telecommunications, some respondents speculated that business travel would have increased by 30-50 per cent.'

For this option assessment, long-distance telecommuting is assumed, on average, to cause around 20 per cent of domestic air travellers to have around 25 per cent less air travel per annum (relative to travel patterns holding under a base case scenario) – where both assumptions are highly speculative, and the resulting long term degrees of adoption could be far lower or higher. It is more likely that these estimates are conservative, since future improvements to video-conferencing could enable substantial reductions to current business travel volumes.

Under these assumptions, possible 2050 abatement is thus roughly estimated at about 0.9 Mt per annum (for 'individual' abatement); and in the aggregate scenario's ordering, about 0.3 Mt per annum.

High Speed Rail

Category	Option	Adoption fraction	Market affected	Market emissions (2050 Mt FFC CO_2e)	Savings fraction	2050 Abatement (Mt FFC CO_2e)

Estimated 'Individual' abatement potential

Aviation demand	High Speed Rail	0.14	Domestic aviation	17.4	0.71	1.7

'In sequence' calculated contribution to aggregate abatement

Aviation demand	High Speed Rail	0.15	Domestic aviation	5.1	0.17	0.1

For this last step in the Aggregate Scenario's list of options (see Table 4), base case aviation demand reduction is considered, due to the provision of long-distance high speed rail.

Strategic studies on the possible implementation of a High Speed Rail (HSR) network on the east coast of Australia are currently being conducted, where the results for this option assessment rely on demand projections provided in the first phase of that process – from the report *High Speed Rail Study – Phase 1* (AECOM et al. 2011) prepared for the Department of Infrastructure and Transport, to assess the likely range of costs, identify potential corridors and stations, estimate the potential future market demand for HSR, and consider potential social and regional development impacts of a HSR network.

This study assessed a network with major stations in Brisbane, Sydney, Melbourne and Canberra, stating that:

> 'Patronage demand analysis suggests that central business district (CBD) locations would be the major trip generator and attractor in each city. Stations closest to the CBD would generate the most demand for a HSR network.'

Furthermore, the Phase 1 study (AECOM et al. 2011 pg. v) confirmed that inter-city (non-stop) running times could be expected as approximately:

- Three hours between Brisbane and Sydney and Sydney and Melbourne
- Forty minutes between Newcastle and Sydney
- One hour between Sydney and Canberra

The AECOM et al. (2011) patronage demand forecasts (assuming inter-city HSR fares comparable with inter-city air fares) suggest that by 2036, 54 million people may use the proposed HSR network each year (though with regional demand, not typically displacing much air travel, representing the largest component of this total patronage).

For estimating likely reductions in aviation demand, the long-distance component of the total patronage is key. Based on the patronage demand forecasts summarised in Table 3.9 (AECOM et al. 2011, pg. 41), which gives separate results for 'Inter-city patronage' and 'Regional patronage' projections, this assessment uses a 2050 forecast for long-distance trips on HSR as equating to approximately 25 billion passenger kilometres per annum. This projected amount of likely HSR long-distance travel is assumed to have been performed by domestic aviation in the base case scenario (where 25 billion pkm is around 14 per cent of the base case aviation demand projection for 2050 – or around 15 per cent of the residual market after the demand reductions of the teleconferencing option in the previous aggregation step).

High speed rail will typically offer significant energy savings per passenger over air travel (e.g. see Brown 2010, *Revolutionary Rail,* Scientific American, May 2010, pg. 38) – though in the aggregation sequence the calculated emission advantages of aviation and passenger rail travel have closed significantly, primarily due to the strong abatement action of biofuels replacing Avtur use in an earlier option step.

Under the scenario inputs, possible 2050 net abatement is roughly estimated at about 1.7 Mt per annum (FFC direct CO_2 equivalent, for 'individual' abatement from a HSR network); and in the aggregate scenario's ordering (after both the 'market emissions' and the 'savings fraction' get reduced by earlier option steps), a net 2050 contribution to aggregate sectoral abatement of about 0.1 Mt per annum.

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