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The Australian Low Carbon Transport Forum – Estimating emission abatement potential for Australian transport

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Abstract

The Australian Low Carbon Transport Forum (ALCTF) - initiated by a project secretariat comprising ARRB Group, BITRE and CSIRO - was organised to draw together knowledge on possible options for transport emission abatement, with the participation of a wide range of government, industry, academic and other research organisations. The overall aims of the ALCTF were to: generate a list of options that could significantly reduce greenhouse gas emissions from the Australian transport sector; identify the potential magnitude of such emission reductions for each option, both individually and when combined; examine challenges to achieving the options' full potential and investigate any uncertainties, especially concerning their likely effectiveness.

A wide range of emission abatement prospects were considered, covering vehicle and fuel technologies, infrastructure improvements, travel demand management, mode shifts and other behavioural change. This paper briefly describes the ALCTF workshop process and option analysis methodologies, including how the estimated levels of potential abatement were calculated for each of the options examined by the ALCTF. Furthermore, a straightforward aggregation process is outlined, illustrating how the various abatement contributions were aggregated into an estimate for the maximal potential reduction, by 2050, across the Australian domestic transport sector, from a full package of measures – where 'maximum' abatement potential here means the amount of future 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, while allowing for possible overlaps or interactions of the various options' effects.

1. Introduction

The Australian Low Carbon Transport Forum (ALCTF) was organised (by a project secretariat comprising ARRB Group, BITRE and CSIRO) in an effort to bring together a wide range of knowledge on greenhouse gas abatement options for the Australian transport sector, and explore just how deeply future emissions could plausibly be cut across the sector. With the participation of around thirty organisations (ranging across government, industry, academic and other research agencies), a set of emission abatement prospects were considered and evaluated, covering the areas of vehicle and fuel technology, infrastructure improvements, travel demand management, modal shift and various other behavioural changes. This paper, which outlines the ALCTF process, and the methodologies used to analyse the feasibility of the different options, essentially summarises parts of a detailed report on the project's main results, *Greenhouse gas abatement potential of the Australian transport sector: Technical Report* (Cosgrove et al. 2012).

Basically, the aims of the ALCTF were to generate a comprehensive list of possible options for reducing greenhouse gas emissions from the Australian transport sector; and to identify how significant potential emission reductions could be, both for each option individually and when combined as an aggregate set of measures. The ALCTF process also strove to examine any obstacles or challenges to achieving the options' full potential, and to investigate any uncertainties or knowledge gaps, especially concerning the options' likely effectiveness, timing or practicality.

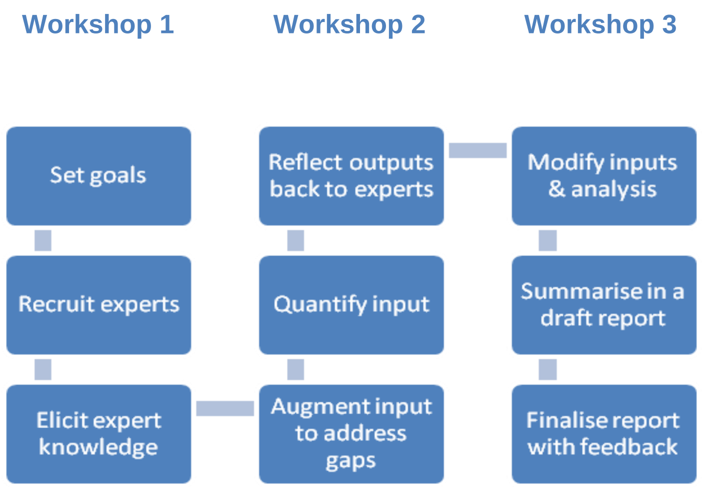
2. Workshop overviews

The core of the ALCTF process consisted of a series of workshops, with a diverse range of forum participants contributing a wide variety of expert knowledge or advice on possible abatement opportunities[1]. Between July and November 2011, three workshops (one each in Melbourne, Sydney and Brisbane) were conducted, comprising:

- Workshop 1 – whose principal activities included outline of the project, sharing of the group knowledge base (amongst the assembled transport industry stakeholders); brainstorming of possible abatement options and discussion of their potential, and identifying initial knowledge gaps and general strategies for addressing them
- Workshop 2 – with review of the project secretariat analyses subsequent to the inputs from the previous workshop (including preliminary estimates of the likely quantity of abatement provided by each option), additional information sharing, identifying any remaining uncertainties and the challenges they could represent for the options' implementation
- Workshop 3 – which focussed on reviewing the draft report of workshop analyses, outcomes and findings, and finalising the abatement estimation procedures

The basic ALCTF Workshop process is set out schematically in Figure 1.

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



[1] For a list of the project's participant organisations see the ALCTF *Summary Report* (CSIRO 2012) or *Technical Report* (Cosgrove et al. 2012).

An extensive list of possible abatement options resulted from the initial workshop discussions. These options were then prioritised by the ALCTF participants, with a view to restricting this sizeable preliminary list to an analytically manageable set of measures – a set not only containing those options considered to have the most significant aggregate abatement potential, but also attempting to cover as extensive a range of modal opportunities as deemed feasible to assess.

By Workshop 3, a final package of measures had been developed (listed in Table 1) – incorporating the main transport abatement opportunities assessed throughout Workshops 1 and 2 – with a view to estimating the *maximal* combined impact, of all the selected options acting together, that could be achieved over the longer term. Note that 'maximal' here means the amount of 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.

Table 1's list of transport options is not meant to be exhaustive or prescriptive, and does not claim to contain every single emission abatement measure worthy of consideration. It merely aims to cover 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 the maximum abatement that could potentially be achieved by about 2050 (while roughly maintaining current levels of transport amenity/utility) from an integrated package of transport sector options. Implementing the table's list would entail a range of behavioural and technological changes, both for the transport sector and across the wider Australian community, involving: policies such as urban road pricing or the control of grossly polluting vehicles; enhancing vehicle fuel efficiency and accelerating uptake of technology prospects (such as electric vehicles or second-generation bio-fuels, for which eventual fleet penetration will partially depend not only on the operation of other policy measures, but as well on the resulting future trends in fuel, vehicle and infrastructure prices[2]); and even some longer-term lifestyle changes (such as resulting from workplaces allowing greater use of telecommuting or the greater adoption of walking following urban re-design).

Over the period spanned by the workshops, significant work was undertaken by the Project Secretariat to collate the available material/information (both from workshop participants and the existing literature), extend and/or revise initial estimates of possible degrees of adoption and technical potential for the various options, and thus progressively improve quantification of the maximum abatement capability of each option.

Through various scenario-setting discussions, particularly during Workshop 2, the ALCTF participants had come 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. Prior to Workshop 3, the Project Secretariat thus concentrated on investigating how the selected greenhouse gas abatement options might interact when combined. All subsequent ALCTF analyses considered the options both individually (as stand-alone alternatives) and as part of an aggregate package of measures

[2] Note that the action of various supplementary measures may be required for the actual realisation of the listed options, even if such measures do not explicitly appear in Table 1 (including some options suggested during the early phases of the ALCTF, but not specifically discussed beyond the first workshop), especially any other measures that would influence eventual prices of fuels and vehicle technologies or otherwise serve to enhance the action of the main options selected. Note also that policy options impacting *directly* on transport 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, recent Treasury modelling (Commonwealth of Australia 2011a) and Graham & Reedman (2011).

(allowing as much as possible for their likely intersections). So Workshop 3, as well as reviewing updated versions of the individual impact assessments for each option, also discussed preliminary results of an 'Aggregate Scenario' (aimed at evaluating the maximum abatement technically feasible by 2050 from the chosen options all acting together).

Table 1: Workshop 3 package of measures: Order of evaluation for Aggregate Scenario

Category	Option
1. VEHICLE AND FUEL TECHNOLOGY	
Light Vehicles	Electric/plug-in cars
	Fuel super-efficiency
	Vehicle downsizing
	Biofuels
Trucks	Engine efficiency improvements
	Low rolling resistance
	Regenerative braking
	Electric trucks
	Biofuels
Aviation	Technology advance
	Biofuels
Maritime	Technology advance
	Bio-fuels
Rail	Technology advance
	Bio-fuels
Bus	Technology advance
	Electric buses
	Biofuels
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
	'Performance Based Standards' (PBS) trucks
All road vehicles	Gross polluter control
4. URBAN TRANSPORT	
Urban vehicle demand	Urban form/design
Urban Public Transit (UPT - 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
	Road 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

Workshop 3 performed a detailed review of the 2050 abatement valuations, including any proposed adoption fractions for particular options, the extent of the transport sub-sectors or markets likely to be most affected by the action of each option (together with estimates of future emission levels due to those markets/activities), and the estimated emission savings fraction each option could potentially apply to its market. This review, having to consider the options both individually (as alternatives each acting in isolation) and as part of the aggregate package (accounting for their possible interactions), concentrated on identifying remaining knowledge gaps – especially any key uncertainties that might affect the existing calculations and impact on an option's estimated scale or relative position on an overall abatement curve. Workshop participants had also been asked to consider likely co-benefits and disbenefits for each option[3], and for their views on how much of a challenge possible social or economic constraints might pose to the successful adoption of the various abatement options.

The straightforward abatement estimation method chosen by the ALCTF is outlined in the next section, and the primary results of the abatement evaluations (finalised using iterative feedback between the Project Secretariat and the ALCTF participants) are presented in the following Section 4.

3. Abatement estimation

Essentially, the amount of abatement an option will achieve is dependent on 1) its level of eventual adoption in a given segment of the transport sector, 2) the existing greenhouse gas emissions in that segment and 3) how effective it is in reducing emissions relative to existing operating conditions.

[3] There are substantial co-benefits that could arise from many of the transport sector abatement options (e.g. improved urban air quality or road safety enhancements). The existence of such co-benefits means that options assessed here as having a smaller relative contribution to aggregate *greenhouse gas abatement* may rank more favourably when their *total net benefit* is assessed by policy makers, businesses or travellers. Some specific disbenefits to society, that might arise if implementation of low carbon transport options is not managed well, include possible loss of vehicle amenity, unfavourable land use changes or higher average transport costs. For further discussion of such issues see the ALCTF *Summary Report* (CSIRO 2012).

A calculation of expected abatement has to be made relative to some projection of likely future conditions, usually referred to as a *reference* or *base* case. Since the abatement estimates are here calculated in relation to projections of 2050 transport emissions or vehicle fuel intensities (under a 'base case' scenario), rather than current levels, the particular specification of that 'reference' scenario has a significant bearing on the resulting calculations. For example, any technological prospect assumed to achieve substantial future market share even under business-as-usual trends may have only a slight 2050 'abatement potential' estimated for any extra market penetration (i.e. relative to the reference case) even if offering large efficiency gains relative to current practices.

Given the importance of the chosen reference case to the abatement estimation process, the next sub-section presents a summary of the specific projections to 2050 (of domestic transport sector activity) used in the study.

3.1 Reference case emission trends

The particular reference scenario adopted for the ALCTF assessments used base case transport projections developed by the Bureau of Infrastructure, Transport and Regional Economics, by suitably adapting their previously published results (BITRE 2010).

The BITRE 'Base Case 2010' projections were estimated using primarily 'business-as-usual' (BAU)[4] 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 (i.e. in the absence of any further policy intervention to reduce transport emissions) in travel behaviour and vehicle technology. Reference 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 (Treasury 2010a, 2010b), with national population forecasts reaching almost 26 million persons by 2020 and about 36 million persons by 2050. Future values for crude oil prices were based on extrapolations of reference scenario trends given in the International Energy Agency's *World Energy Outlook 2009* (IEA 2009a), with prices reaching around $US120 per barrel (in constant dollars) by 2030, and averaging around $US130 per barrel over the longer term.

Road vehicle use per person is expected to exhibit a slight upward trend to 2020, as the residual damping effects of the Global Financial Crisis gradually wear off. However past 2020, road vehicle kilometres per person will tend to *saturate* if long-term structural trends (identified by BITRE studies for many Australian transport tasks) continue to hold. For example, see Figure 1, which plots per capita urban passenger travel against average income levels. Note how markedly the growth rate in urban car travel per person has reduced over time; implying an upper bound to per capita urban travel could effectively apply within the next decade or so, and that daily travel levels in Australian are likely to increase more slowly in the future than for the long-term historical trend (becoming roughly proportional to the future rate of population increase).

However, other aggregate activity within the Australian transport sector is still likely to grow significantly over the projection period, since such saturating tendencies are not yet evident in long-distance passenger travel or freight movement trends. The base case projections have continuing strong growth in domestic air travel (with an average task increase of about 2.8 per cent per annum out to 2050) and total freight tonne-kilometres (averaging growth of close to 2.3 per cent per annum over the forecast period 2010-2050).

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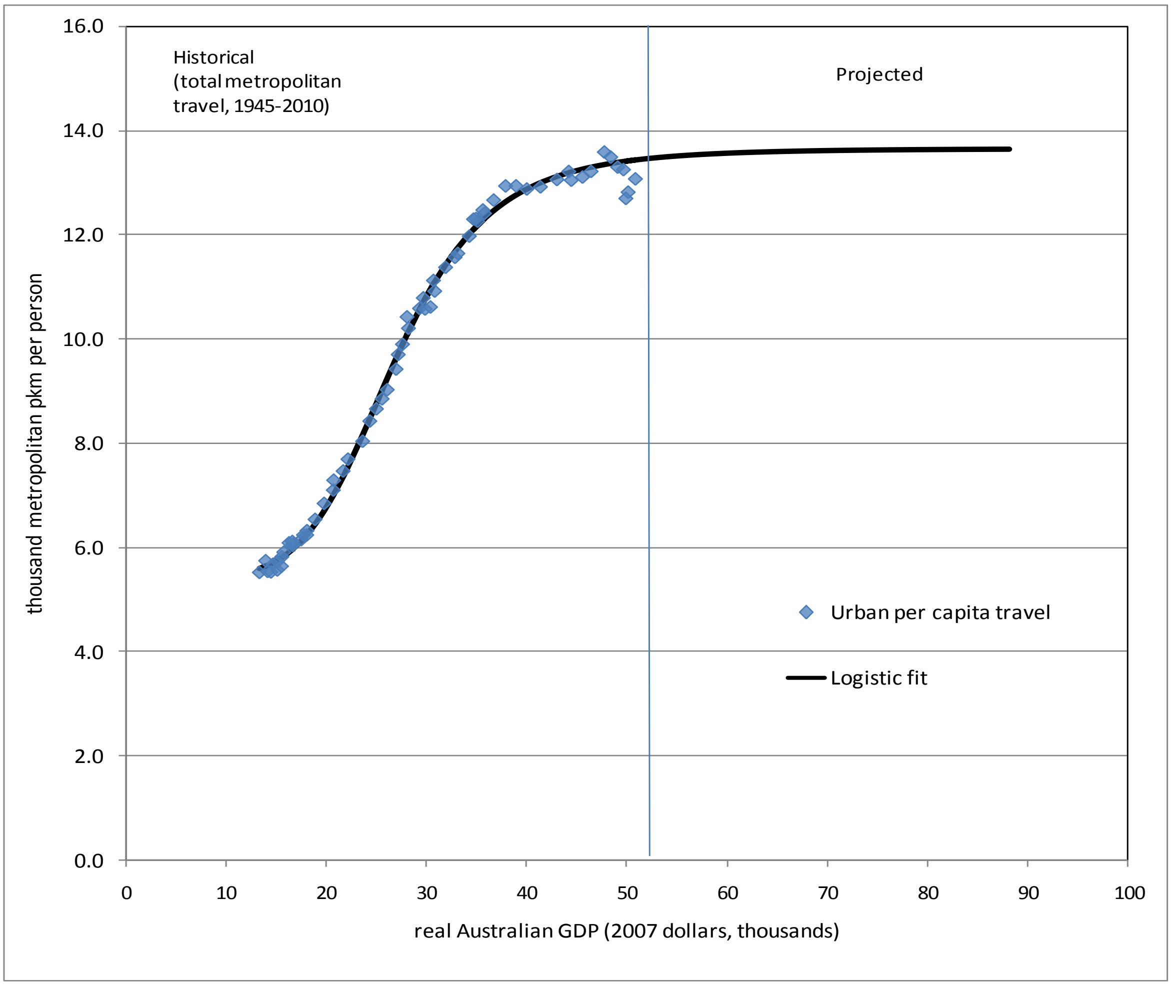
[4] The particular base case scenario used for the BITRE 2010 projections (and used for DCCEE 2010) could be more fully described as a 'base case with measures', in that the scenario also incorporated the impact of the likely progress, over the medium term, of various greenhouse gas abatement measures that Australian governments had already (i.e. by mid-2010) implemented or fully framed.

Figure 1: Relationship of per capita Australian urban travel to per capita income



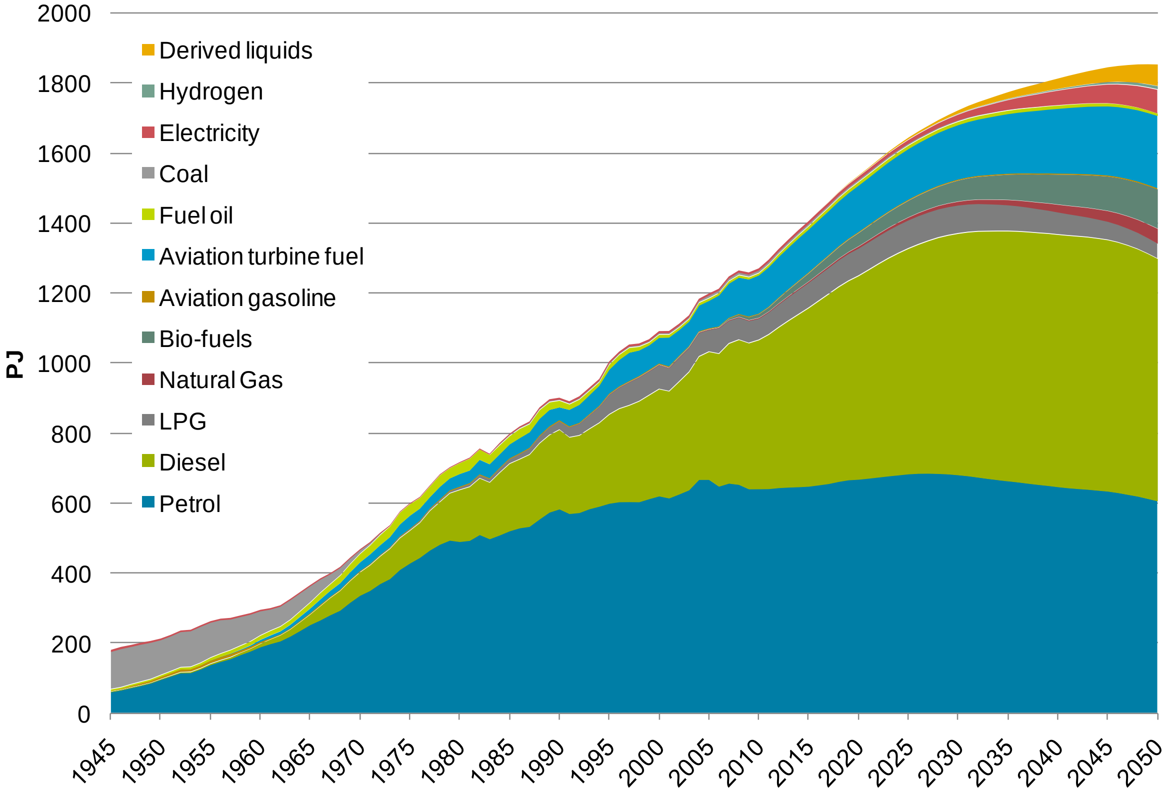
Note: For each data point: y-axis value refers to total annual passenger travel (in passenger-kilometres) within the State and Territory capital cities, divided by the resident metropolitan population (as at each year ending 30 June, totalled across the capital city Statistical Divisions); x-axis value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

Sources: BITRE estimates, Cosgrove (2011).

Under the BAU scenario assumptions, expected innovation in vehicle and engine technology, leading to gradual improvements in average fuel efficiency (along with assumed increases in electricity use by transport) – combined with the moderate growth trends likely for short-distance travel in the future (as displayed in Figure 1) – serve to roughly stabilise aggregate end-use energy consumption from about 2040 on. See Figure 2 for the reference scenario projections (of energy consumption in petajoules, where PJ = 10^{15} joules) covering Australian civil domestic transport activity.

Since many of the options being assessed by the ALCTF involve possible changes to fuel supply, solely end-use emission values are not fully suitable for these analyses. For a more complete picture of total emissions output due to Australian transport (especially since end-use values do not include any of the emissions due to electricity use), estimates of full fuel cycle (FFC) emissions are derived for these evaluations. 'Full fuel cycle' values refer to the inclusion of emissions released during transport fuel supply and processing (including from petroleum refining or biofuel production), and during power generation (for electric vehicles or railways), as well as from direct fuel combustion.

Figure 2: Energy end-use for Australian civil domestic transport – Base Case projections to 2050 by fuel type, for indicative energy mix



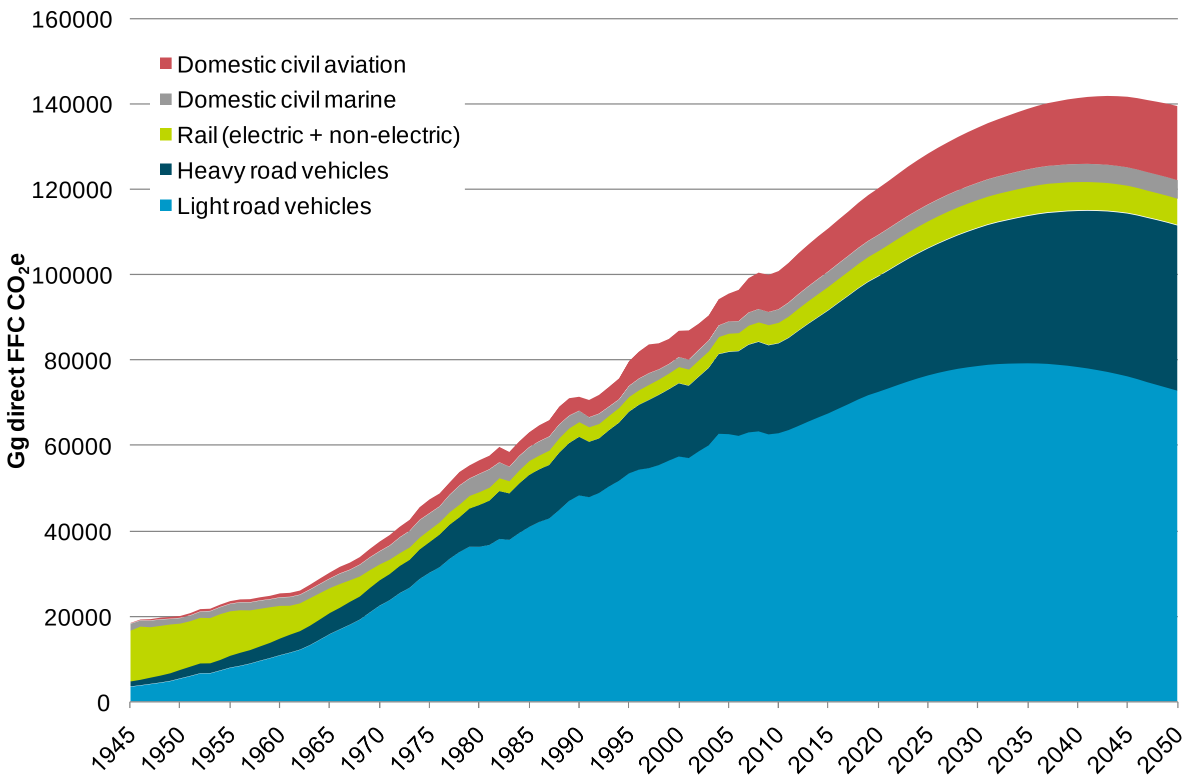
Source: BITRE (2010).

This means that when any alternative fuels are considered, all emissions associated with their supply are taken into account, which is important since some fuels have considerable upstream emissions, but very low or zero emissions during their use. For example, carbon dioxide emissions from the use of biofuels are traditionally assigned a zero level for emission inventory accounting purposes, assuming that the amount of carbon dioxide from their direct combustion will be reabsorbed when the biofuel feedstock is regrown. However, with FFC evaluations, emissions associated with cultivating, harvesting, transporting, processing and converting the feedstock biomass into biofuel are also accounted for, providing the estimates of *net* emissions from biofuel consumption used in this study.

The upstream emission intensities of various fuels are not likely to remain constant, but rather are expected to improve considerably over time. For example, it is assumed in these assessments that Australian electricity generation becomes increasingly less carbon intensive, and that biofuels become progressively sourced more from non-food feedstocks typically requiring less resources to produce (such as fertiliser, conversion energy or necessary land area).

Specifically, the FFC values derived for the ALCTF assume that the provision of electricity decarbonises over time consistent with Treasury modelling on the expected impacts of the proposed carbon pricing scheme (Commonwealth of Australia 2011a, 2011b) – including estimates for how induced technology improvements and more renewable generation should serve to significantly reduce the carbon intensity of the generation sector. In the Treasury 'core policy scenario' (Commonwealth of Australia 2011a), generation emission intensity (in tonnes of CO_2 per megawatt-hour of electricity delivered) is forecast to reduce by about 30 per cent over the next 20 years, and by around 75 per cent by 2050. Such a reduction in emission intensity significantly improves the appeal of electric vehicles as a transport abatement option.

Figure 3: 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, as well as from fuel combustion. Net emissions for biofuels are also estimated here.

'*Aviation*' is all civil domestic aviation (i.e. including general aviation, but excluding military aircraft).

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

'Light Road Vehicles' include all passenger cars and Sports Utility Vans, Light Commercial Vehicles and motorcycles. 'Heavy road vehicles' include all trucks (rigid and articulated) and buses.

Sources: BITRE estimates, BITRE (2009, 2010), Cosgrove et al. (2012).

In accordance with current DCCEE National Greenhouse Gas Inventory specifications for reporting of carbon dioxide equivalent (CO_2e) values, the calculations here 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). The FFC emission projections for the base case scenario, across the Australian civil domestic transport sector, are given in Figure 3. Aggregate emission volumes[5] for the reference case in 2050, at approximately 140 thousand gigagrams of direct CO_2e (where Gg = 10^9 grams, equivalent to thousand tonnes), are approximately 38 per cent higher than 2010 levels. These results differ slightly from the

[5] Note that both the reference volumes and the abatement calculations would differ somewhat if the CO_2e values were also to include: the indirect warming effects of gases like the ozone precursors (such as carbon monoxide, nitrogen dioxide and volatile organics); complex net aerosol effects (such as due to the black carbon portion of vehicle particulate emissions); fugitive releases of fluorocarbons from motor vehicle air-conditioners; altitude effects for various non-CO_2 emissions (that serve to significantly increase the relative warming contribution of aviation); fuel use by international transport to and from Australia; or any of a wide range of additional life-cycle emissions, (e.g. relating to vehicle manufacture or transport infrastructure operation). For some discussion and quantification of these issues, see Chapter 5 of BITRE 2010 or pp. 28-31 of Cosgrove et al. 2012.

FFC base case values provided in BITRE (2010), since the original BITRE scenario assumed a more conservative de-carbonisation rate for Australian electricity generation.

3.2 Abatement example

Having assembled the options (as listed in Table 1), they were assessed using the simple (three element) framework described at the start of this section, and demonstrated by Table 2, which presents (as an example) the summary abatement calculations for the fourth option in the Table 1 list, the expanded use of biofuels in light vehicles.

The first two columns identify the specific option being considered (biofuel use) and to which of the seven major categories (that Table 1 has been grouped into) the option belongs ('Vehicle and fuel technologies'). The next two columns give the 'market' or particular transport activity targeted or affected by the option (light vehicle use) and the assumed 'adoption fraction' or proportion of the 2050 base case market that is altered by the option's effects (given in net terms, i.e. relative to any adoption already assumed in the base case)[6]. Referring specifically to the top row of the Table 2 estimates, the 5th and 6th columns then give the size of the 'market emissions' (where the base case projections have light vehicles accounting for 72.9 million tonnes of direct FFC CO_2 equivalent emissions in 2050) and the estimated emissions 'savings fraction' (i.e. the relative difference between the biofuel option and standard petroleum use)[7]. Finally, the last column shows the result of the abatement potential calculation, by multiplying the three estimation elements together – in the top row's case, the 0.62 'adoption fraction' times the 72.9 Mt 'market emissions' times the 0.65 'savings fraction' yielding an estimated '2050 Abatement' of 29.4 megatonnes of FFC CO_2e.

Table 2: Abatement estimates, Biofuels for light vehicles

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

This particular part of the options list assumes that a large proportion of non-electric light vehicles are capable of being run on biofuels/biofuel blends by 2050. For the specific scenario evaluated here, the major share of this use is assumed to be bio-derived ethanol (with an assumed biodiesel market share of about 10%), from a range of currently available sources (1st generation biofuels) and projected future feedstock materials (2nd generation biofuels). Note that the various biofuel options have some of the greater uncertainty levels

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[6] For example, 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.

[7] Depending on the process, estimated abatement potentials for biofuels cover a wide range, where a mid-range future abatement fraction of 0.65 has been chosen for this scenario, roughly representative of emission factors (as provided in studies such as Farine et al. 2011) for ethanol from the use of crop stubble as a feedstock.

associated with their 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[8].

So considered as a stand-alone or individual option, the top row of Table 2 indicates that 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. Alternately, the bottom row of the table gives the corresponding three-element calculation for the option when considered 'in sequence' (i.e. as a single step in the options aggregation process, to derive a total package abatement, summed across all the options acting together).

Since directly summing all the individual abatement potentials of the various measures does not give a meaningful answer (in fact, as later shown by Table 3, totalling substantially greater than 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), in order to gain a more realistic indication of their overall potential impact.

In particular, the 'market emissions' value (5th column of Table 2) is no longer the *whole* base case level for 2050, but the *residual market* resulting from the actions of all the options higher in the Table 1 list (i.e. the amount of projected light vehicle emissions remaining after each preceding option's abatement, in the aggregate sequence, reduces the amount of emissions for the other proceeding options to act upon). For example, the residual market for the 'in sequence' calculation of Table 2 has been reduced by the three options higher in the Table 1 aggregation list (i.e. with the further electrification, vehicle 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), meaning its 'in sequence' contribution to the aggregate abatement (at about 12 Mt CO_2e) in 2050 is substantially less than its individual potential by then.

This method of estimation for the Aggregate Scenario thus entails setting an order, for calculating the successive steps for each option's contribution; with the sequencing given in Table 1 (options summed from the top of the table down) being agreed amongst workshop participants as a reasonable evaluation order (where the category with the largest aggregate abatement potential, 'Vehicle and Fuel Technology', was selected to be first in the listing). The particular order chosen has no objective meaning, and changing this sequence would not alter the final estimate for aggregate abatement, just the individual steps during its computation. That is, if an option were to be moved down the evaluation list, its resulting 'in sequence' abatement estimate would tend to reduce, and any options moved up the list would typically have their 'in sequence' values increase accordingly. The 'in sequence' abatement value for any particular measure (as provided in Table 4) is thus generally not all that meaningful – and if trying to gauge the actual abatement potential of a specific option one is better off looking at the 'individual' (or stand-alone) abatement values (as provided in

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[8] That is, the estimated level of possible abatement is predicated on there being an adequate supply of affordable second-generation biofuels in the future. This will be subject to technological development outcomes and to competing needs for biomass possibly limiting transport sector availability. Based on CSIRO assessments of likely future availability of domestic biofuels (e.g. Farine et al. 2011), the ALCTF scenarios place 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 (after allowing for likely *sustainable* Australian feedstock capacities and roughly equivalent extra volumes from imports).

Table 3) – yet the various 'in sequence' estimates are summarised here so that interested readers can roughly follow the calculation of the option combination/aggregation process[9].

4. Abatement results

Table 3 gives the results derived for the individual impact of each option 'in isolation' (i.e. the abatement impact that the option would have if all else stayed the same as the reference case), tabulated separately for each of the 47 abatement possibilities selected for ALCTF assessment. Though this initial approach allows us to see each option's potential without the operation of any other abatement measures, note that the 'cumulative total' column in Table 3 ends up with a final reduction value of around 220 Mt CO_2e, tallied over 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 significantly less, at around 140 Mt CO_2e.

This motivates the more detailed aggregation investigation outlined in the previous section, with the estimation results given in Table 4 (providing values for the 'in sequence' contribution, following the chosen evaluation order, to the aggregate abatement potential from each of the selected options). Table 4 shows that the sequential analysis of the ALCTF Aggregate Scenario yields a total sectoral abatement estimate of about 108 Mt CO_2e per annum by 2050 (i.e. the abatement potential of all the options acting together is roughly equivalent to a 77 per cent reduction in the projected level of transport sector emissions from the reference scenario).

The estimated abatement values for both the 'in isolation' assessments (as given in Table 3) and the 'in sequence' contributions (as given in Table 4) are plotted in Figure 4, by market/activity affected, for each of the 47 emission saving prospects considered by the ALCTF (in terms of megatonnes of full fuel cycle direct CO_2 equivalent capable of being reduced per annum by 2050, relative to BAU assumptions), demonstrating the significant potential of enhancements to vehicle and fuel technologies.

The divergence between the Base Case trend (for total greenhouse gas emissions from Australian domestic transport) and levels that could potentially hold, following implementation of the package of options comprising the ALCTF Aggregate Scenario, widens over time (as displayed in Figure 5, which also shows the estimated modal composition resulting from the options' combined actions). Under such combined and concerted action, transport sector emissions are projected to fall to around 32 Mt CO_2e per annum by 2050.

5. Conclusions

Based on extensive input from transport experts, a representative set of 47 individual abatement options for the transport sector were examined in detail, and had their maximal potential for future emission reductions assessed. These included a large number of fuel and vehicle technologies (especially concerning vehicle electrification and biofuel use), urban transport measures, new and alternative infrastructure, and options to modify behaviour via regulation and price signals. The large number of available options identified by the forum testifies to how complex and diverse the transport sector is.

The ALCTF process has demonstrated that it should be technically feasible for Australian domestic transport to have its aggregate sectoral emissions decline over time, under the action of an integrated package of measures, to be around 64 per cent lower than year 2000 levels by 2050, without severely compromising overall transport utility. This reduction could be obtained using a range of technologies either currently available or likely to be commercialised in the near to medium term (assuming certain research or infrastructure

[9] For more detail on the option assessments see the ALCTF *Technical Report* (Cosgrove et al. 2012).

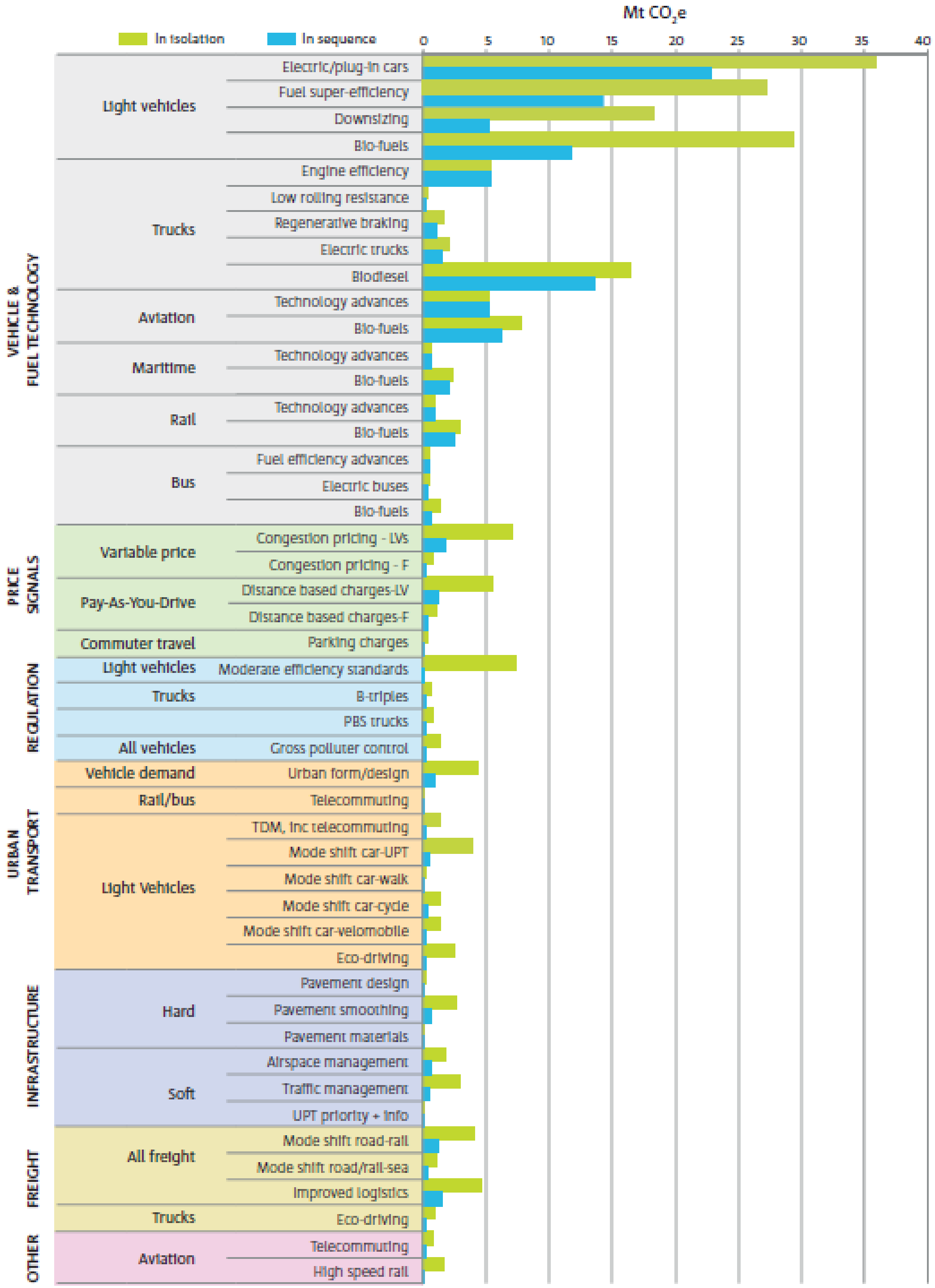
Table 3: Individual (in isolation) option assessments

Category / Mode / Option			'Individual' abatement (2050 Mt FFC direct CO_2e)	'Individual' abatement Cumulative total (2050 Mt FFC direct CO_2e)	Net adoption fraction	Modal sub-sector or market affected	'Individual' market emissions (2050 Mt CO_2e)	Estimated savings fraction
1. VEHICLE and FUEL TECHNOLOGY								
	Light vehicles	electric/plug-in cars	35.8	35.8	0.61	light vehicles (LV)	72.9	0.8
		fuel super-efficiency	27.3	63.1	1.00	light vehicles	68.1	0.40
		downsizing	18.2	81.3	1.00	light vehicles	72.9	0.25
		bio-fuels	29.4	110.7	0.62	light vehicles	72.9	0.65
	Trucks	engine efficiency	5.4	116.1	1.00	Trucks	36.1	0.15
		low rolling resistance	0.4	116.4	0.10	Trucks	36.1	0.1
		regenerative braking	1.6	118.1	0.90	Urban rigids	9.1	0.2
		electric trucks	2.0	120.1	0.30	Urban rigids	9.1	0.75
		biodiesel	16.4	136.6	0.70	Trucks	36.1	0.65
	Aviation	technology	5.2	141.8	1.00	domestic aviation	17.4	0.3
		bio-fuels	7.8	149.6	0.75	domestic aviation	17.4	0.6
	Maritime	technology	0.7	150.3	1.00	domestic shipping	2.3	0.3
		bio-fuels	2.41	152.7	0.85	all water craft	4.4	0.65
	Rail	technology	0.9	153.6	1.00	all rail	6.3	0.15
		bio-fuels	3.0	156.6	0.85	non-electric rail	5.4	0.65
	Bus	technology	0.5	157.1	1.00	buses	2.7	0.2
		electric buses	0.5	157.7	0.35	urban buses	1.9	0.8
		bio-fuels	1.4	159.0	0.82	buses	2.5	0.65
2. PRICE SIGNALS								
	Variable price	road/congestion pricing	7.0	166.1	0.70	Urban light vehs	43.7	0.23
		(time and area based)	0.9	166.9	0.60	Urban trucks	14.3	0.1
	Pay-As-You-Drive	distance based charges	5.5	172.4	1.00	All light vehs	72.9	0.075
		(Rego, insurance etc)	1.1	173.5	1.00	Trucks	36.1	0.03
	Commuter	parking charges	0.4	173.9	1.00	Urban light vehs	43.7	0.01
3. REGULATION								
	Light Vehicles	moderate L/100km standards	7.3	181.2	1.00	light vehicles	72.9	0.1
	Trucks	B-triples	0.6	181.8	0.55	B-doubles	11.3	0.1
		PBS trucks	0.8	182.6	0.22	Trucks	36.1	0.1
	All vehicles	gross polluter control	1.41	184.0	0.90	non-elec vehicles	104.3	0.015
4. URBAN TRANSPORT								
	Urban vehicle demand	urban form/design	4.35	188.4	0.50	Urban vehicles	58.0	0.15
	Rail/bus	telecommuting	0.03	188.4	0.05	Urban public transport	2.5	0.25
	Light vehicles	TDM, inc telecommuting	1.31	189.7	0.10	Urban light vehs	43.7	0.3
		mode shift car-UPT	3.9	193.6	0.15	Urban light vehs	43.7	0.59
		mode shift car-walk	0.24	193.8	0.30	Urban LV trips < 2km	0.8	1.00
		mode shift car-cycle	1.44	195.3	0.20	Urban LV trips < 10km	7.2	1.00
		mode shift car-velomobile	1.31	196.6	0.10	Urban LV trips < 20km	13.8	0.95
		eco-driving	2.5	199.0	0.45	light vehicles	68.1	0.08
5. INFRASTRUCTURE								
	Hard	pavement design	0.18	199.2	0.20	road construction	3	0.3
		pavement smoothing	2.68	201.9	0.80	All vehicles	111.7	0.03
		pavement materials	0.11	202.0	1.00	road resurfacing	1	0.11
	Soft	airspace management	1.7	203.7	1.00	domestic aviation	17.4	0.1
		traffic management	2.99	206.7	0.50	All urban vehicles	59.9	0.1
		UPT priority + info	0.12	206.9	0.50	UPT	2.5	0.1
6. FREIGHT								
	All freight	mode shift road-rail	4.0	210.9	0.40	intercapital trucking	14.7	0.68
		mode shift road/rail-sea	1.1	212.0	0.12	interstate rail / trucks	11.9	0.76
		improved logistics	4.7	216.6	0.50	interstate rail / trucks	37.3	0.25
	Heavy vehicles	eco-driving	0.9	217.5	0.50	heavy vehicles	38.8	0.05
7. OTHER								
	Aviation	telecommuting	0.9	218.4	0.20	domestic aviation	17.4	0.25
	Rail	High Speed Rail	1.7	220.1	0.14	domestic aviation	17.4	0.71
						total transport - base case	140	
Total 2050 abatement (all measures, inc. infrastructure)			220.1	220.1		inc. pavement materials	144	

Table 4: Aggregate (in sequence) assessment

Category / Mode / Option		'In sequence' abatement (2050 Mt FFC direct CO_2e)	'In sequence' abatement Cumulative total (2050 Mt FFC direct CO_2e)	Net adoption fraction	Modal sub-sector or market affected	'In sequence' market emissions (2050 Mt CO_2e)	Estimated savings fraction
1. VEHICLE and FUEL TECHNOLOGY							
Light vehicles	electric/plug-in cars	22.8	22.8	0.39	light vehicles (LV)	72.9	0.8
	fuel super-efficiency	14.3	37.1	1.00	light vehicles	40.1	0.36
	downsizing	5.1	42.3	1.00	light vehicles	35.7	0.14
	bio-fuels	11.8	54.0	0.82	light vehicles	22.1	0.65
Trucks	engine efficiency	5.4	59.4	1.00	Trucks	36.1	0.15
	low rolling resistance	0.3	59.7	0.10	Trucks	30.7	0.1
	regenerative braking	1.0	60.8	0.90	Urban rigids	7.6	0.15
	electric trucks	1.5	62.3	0.30	Urban rigids	6.6	0.75
	biodiesel	13.6	75.9	0.75	Trucks	27.9	0.65
Aviation	technology	5.2	81.1	1.00	domestic aviation	17.4	0.3
	bio-fuels	6.2	87.3	0.85	domestic aviation	12.2	0.6
Maritime	technology	0.7	88.0	1.00	domestic shipping	2.3	0.3
	bio-fuels	2.0	90.0	0.85	all water craft	3.7	0.65
Rail	technology	0.9	90.9	1.00	all rail	6.3	0.15
	bio-fuels	2.4	93.4	0.85	non-electric rail	4.4	0.65
Bus	technology	0.5	93.9	1.00	buses	2.7	0.2
	electric buses	0.4	94.3	0.35	urban buses	1.5	0.8
	bio-fuels	0.7	95.1	0.82	buses	1.4	0.65
2. PRICE SIGNALS							
Variable price	road/congestion pricing	1.8	96.9	0.70	Urban light vehs	11.3	0.23
	(time and area based)	0.3	97.2	0.60	Urban trucks	4.9	0.1
Pay-As-You-Drive	distance based charges	1.3	98.5	1.00	All light vehs	17.0	0.075
	(Rego, insurance etc)	0.4	98.9	1.00	Trucks	14.0	0.03
Commuter	parking charges	0.1	99.0	1.00	Urban light vehs	8.7	0.01
3. REGULATION							
Light Vehicles	moderate L/100km standards	0.0	99.0	1.00	light vehicles	0.0	0.1
Trucks	B-triples	0.2	99.2	0.55	B-doubles	4.2	0.1
	PBS trucks	0.3	99.5	0.22	Trucks	13.3	0.1
All vehicles	gross polluter control	0.3	99.8	0.90	non-elec vehicles	20.4	0.015
4. URBAN TRANSPORT							
Urban vehicle demand	urban form/design	1.0	100.8	0.50	Urban vehicles	13.3	0.15
Rail/bus	telecommuting	0.01	100.8	0.05	Urban public transport	1.1	0.25
Light vehicles	TDM, inc telecommuting	0.23	101.0	0.10	Urban light vehs	7.8	0.3
	mode shift car-UPT	0.53	101.5	0.15	Urban light vehs	7.6	0.46
	mode shift car-walk	0.12	101.7	0.40	Urban LV trips < 2km	0.3	1.00
	mode shift car-cycle	0.33	102.0	0.25	Urban LV trips < 10km	1.3	1.00
	mode shift car-velomobile	0.30	102.3	0.15	Urban LV trips < 20km	2.1	0.95
	eco-driving	0.23	102.5	0.45	light vehicles	12.7	0.04
5. INFRASTRUCTURE							
Hard	pavement design	0.15	102.7	0.20	road construction	2.5	0.3
	pavement smoothing	0.64	103.3	0.80	All vehicles	26.5	0.03
	pavement materials	0.08	103.4	1.00	road resurfacing	0.7	0.11
Soft	airspace management	0.60	104.0	1.00	domestic aviation	6.0	0.1
	traffic management	0.53	104.5	0.50	All urban vehicles	10.6	0.1
	UPT priority + info	0.07	104.6	0.50	UPT	1.4	0.1
6. FREIGHT							
All freight	mode shift road-rail	1.2	105.8	0.40	intercapital trucking	5.1	0.58
	mode shift road/rail-sea	0.4	106.2	0.11	interstate rail / trucks	4.5	0.79
	improved logistics	1.5	107.7	0.50	interstate rail / trucks	12.0	0.25
Heavy vehicles	eco-driving	0.2	107.9	0.50	heavy vehicles	10.3	0.04
7. OTHER							
Aviation	telecommuting	0.27	108.2	0.20	domestic aviation	5.4	0.25
Rail	High Speed Rail	0.13	108.3	0.15	domestic aviation	5.1	0.17
					total transport - base case	140	
Total 2050 abatement (all measures, inc. infrastructure)		108.3	108.3		inc. pavement materials	144	

Figure 4: Estimated maximum greenhouse gas reduction that could be achieved by selected transport abatement options, considered in isolation and as an in sequence contribution to a transport sector aggregate, by 2050

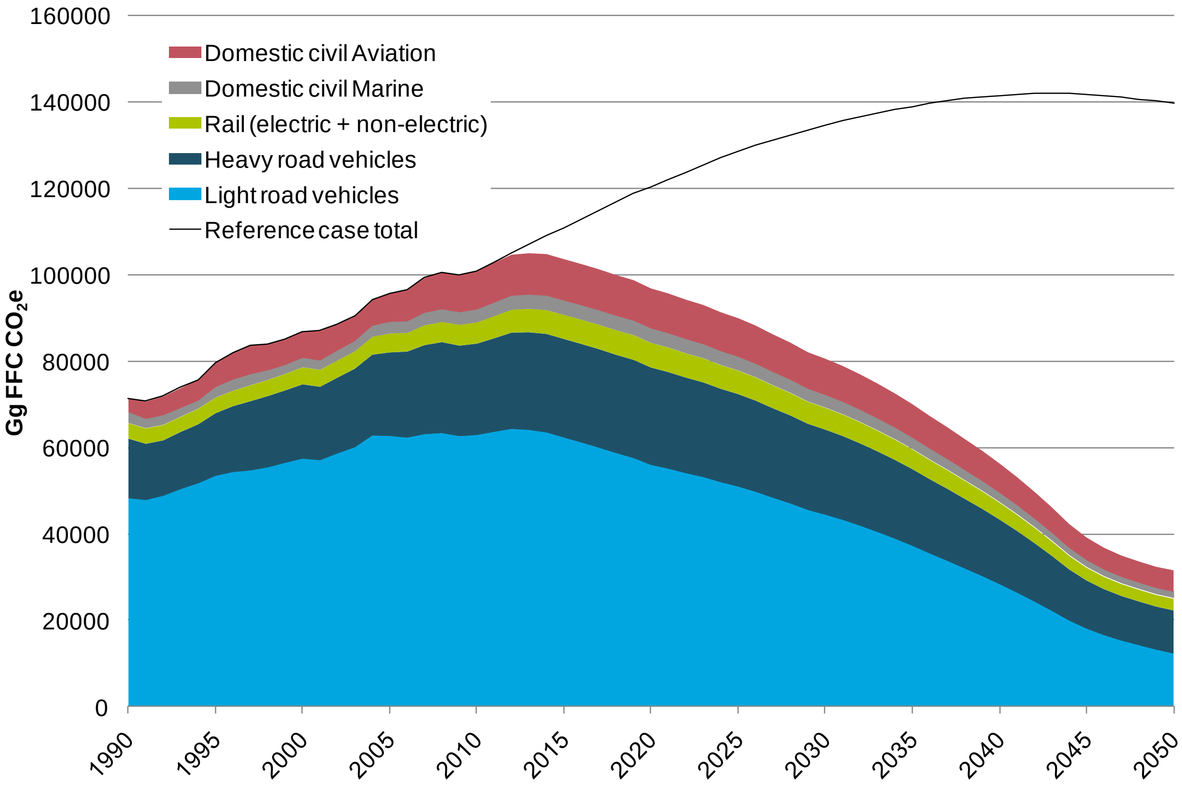


Notes: LV – light vehicle, F – freight vehicle.

'In sequence' values strongly depend on the evaluation order chosen for the option aggregation, and are not necessarily representative of actual individual effects or technical potentials.

Sources: Cosgrove et al. (2012), CSIRO (2012).

Figure 5: Maximum potential abatement projected for Australian transport sector, ALCTF Aggregate Scenario compared to Base Case projections



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, as well as from fuel combustion. Net emissions for biofuels are also estimated here.

'*Aviation*' is all civil domestic aviation (i.e. including general aviation, but excluding military aircraft).

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

'Light Road Vehicles' include all passenger cars and Sports Utility Vans, Light Commercial Vehicles and motorcycles. 'Heavy road vehicles' include all trucks (rigid and articulated) and buses.

Sources: BITRE estimates, BITRE (2010), Cosgrove et al. (2012).

developments progress sufficiently over the coming decades, such as decarbonisation of the electricity grid or the adequate availability of affordable 2nd generation biofuels derived from environmentally sustainable feedstocks), and a variety of standard transport demand management options (such as congestion pricing, improvements to freight logistics or mode changes).

The ALCTF scenarios were assessed primarily independent of explicit cost considerations. However, even though the study did not seek precise quantification of the costs of individual options, it appears that incremental investment in the order of $A5-10 billion per annum (whether public or private, with the major cost components, across the set of options identified here, probably relating to the provision of extra vehicle technology) could be required to implement such a package of abatement measures. Over time, this investment will generally deliver financial benefits, primarily in the form of fuel savings, which are expected to eventually more than offset the incremental costs (i.e. deliver net social benefits over the longer term, with the up-front costs more than balanced by advantages such as reduced fuel consumption, traffic congestion improvements or health benefits from better urban air quality).

The aggregation process conducted here is quite approximate in nature, and there are significant uncertainties surrounding many of the abatement assessments, yet such a collective set of options should certainly offer substantial emission reduction potential, as long as any social or economic obstacles to their implementation can be successfully overcome. For example, ongoing global research, development and industrial deployment are likely to be required to reduce the costs of some options (where high cost levels will serve to delay or slow their adoption). Any future rises in oil prices will tend to act as a significant incentive, accelerating the take-up of some options. It is possible, however, that a combination of rising fossil fuel prices together with government policies complementing their adoption (by addressing particular social or regulatory constraints affecting various options' acceptance) will be required in order to realise the transport sector abatement potentials identified here by the ALCTF.

Abbreviations

ALCTF	Australian Low Carbon Transport Forum
BAU	business-as-usual
BITRE	Bureau of Infrastructure, Transport and Regional Economics
CO_2e	carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
FFC	full fuel cycle
GDP	Gross Domestic Product
Gg	gigagrams, 10^9 grams
Mt	megatonnes, 10^6 tonnes
PBS	Performance Based Standards
PJ	petajoules, 10^{15} Joules
TDM	transport demand management
UPT	urban public transport

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