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**Road transport and climate
change: Stepping off the
greenhouse gas**

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ABSTRACT: Transport is Australia's third largest and second fastest growing source of greenhouse gas (GHG) emissions. The road transport sector makes up 88 percent of total transport emissions and the projected emissions increase from 1990 to 2020 is 64 percent. Achieving prospective emission reduction targets will pose major challenges for the road transport sector. This paper investigates two targets for reducing Australian road transport greenhouse gas emissions, and what they might mean for the sector: emissions in 2020 being 20 percent below 2000 levels; and emissions in 2050 being 80 percent below 2000 levels. Six ways in which emissions might be reduced to achieve these targets are considered. The analysis suggests that major behavioural and technological changes will be required to deliver significant emission reductions, with very substantial reductions in vehicle emission intensity being absolutely vital to making major inroads in road transport GHG emissions.

KEY WORDS: *Climate change; emission targets; fuel efficiency; mode share; public transport.*

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1. Context

Garnaut (2008) has pointed out that greenhouse gas (GHG) emissions have been growing more quickly than was anticipated in the Intergovernmental Panel on Climate Change's Fourth Assessment Report (IPCC 2007). He argues that Australian emission reductions of 70 to 90 percent on 2000 levels are likely to be needed by 2050 under global emission stabilisation scenarios of 550ppm and 450ppm of CO₂-e respectively, in line with the reductions suggested more broadly for high emitting developed economies by Stern (2006). The current Australian 2050 target is for emission reductions of 60 percent on 2000 levels, which is a relatively low reduction in terms of these comparisons.

Transport is Australia's third largest and second fastest growing source of GHG emissions, with total emissions of 65.9 Mt CO₂-e in 2005 accounting for 14 percent of total Australian emissions. The road transport sector makes up 88 percent of total transport emissions, and road transport emissions are projected to increase 64 percent from 1990 to 2020 (Department of Climate Change 2008). While the most efficient national path to emission reduction might involve some sectors cutting their emissions more than others, national emission reductions on the scale indicated will require all sectors to contribute substantially. The larger and faster growing emissions sectors will need to be prominent, otherwise efforts to reduce GHG will be problematic. Road transport can thus be expected to make a significant contribution.

This paper investigates the broad implications of two possible targets for Australian road transport GHG emissions:

- emissions in 2020 being 20 percent below 2000 levels (close to the unilateral position put by European countries to the IPCC Bali Conference, which was 25 to 40 percent below 1990 levels)
- emissions in 2050 being 80 percent below 2000 levels.

Investigating such indicative sectoral targets is not necessarily implying that the transport sector need be required to deliver on changes of the magnitude canvassed solely by behavioural and technological changes that directly reduce transport emissions. For example, emission credits might be cost-effectively obtained by the transport sector from other sectors and/or other countries, in an international emissions trading regime. However, by confronting the possibility that the sector may need to be accountable for reductions of the order of magnitude under consideration, this paper focuses attention on some of the strategic thinking that is needed to plan for the future.

Data is presented on road transport GHG emissions and projections of future emissions, to provide a basis for estimating the scale of reductions that will be needed to achieve the reduction targets indicated. The 2020 target is then discussed, outlining the type and scale of changes that will be required to achieve this result. Six major categories of measures are considered and possible contributions from each are outlined¹. The much tougher 2050 target is then considered, after which the paper presents conclusions, drawing out some key policy implications.

2. Transport greenhouse gas emissions and emission reduction targets

The emission reduction target considered for 2020 is set against the background projection of Australian road transport emissions shown in Figure 1 (drawn from Department of Climate Change 2008). This is a "business-as-usual" projection but allowing for the emission-reducing impacts of a

¹ It should be noted that no attempt has been made to evaluate the relative merits (benefits and costs) of reducing emissions through each of the considered measures, or to trace out precisely how the specific reductions for any given measure would be achieved. Examples of how reductions can be achieved under each of the measures are noted, but there is no attempt to be exhaustive. The estimates should thus be seen as describing possible future emission scenarios that policy makers and planners can use as a foundation for more detailed review of options and outcomes. This approach highlights the immensity of the challenges that are ahead and opens the way for more detailed assessment of specifics.

number of measures that are already in place, such as travel behaviour change programs, gas-conversion programs and alternative fuels. Road transport emissions are projected to grow from 65.9 Mt CO₂-e in 2000 to 88.9 Mt in 2020, an increase of 35 percent (or 64 percent from 1990). The Figure shows that road transport currently accounts for about 88 percent of Australian transport sectoral emissions, a share that is still expected to be about 86 percent in 2020 (e.g. domestic aviation emissions are projected to grow faster than those from road transport).

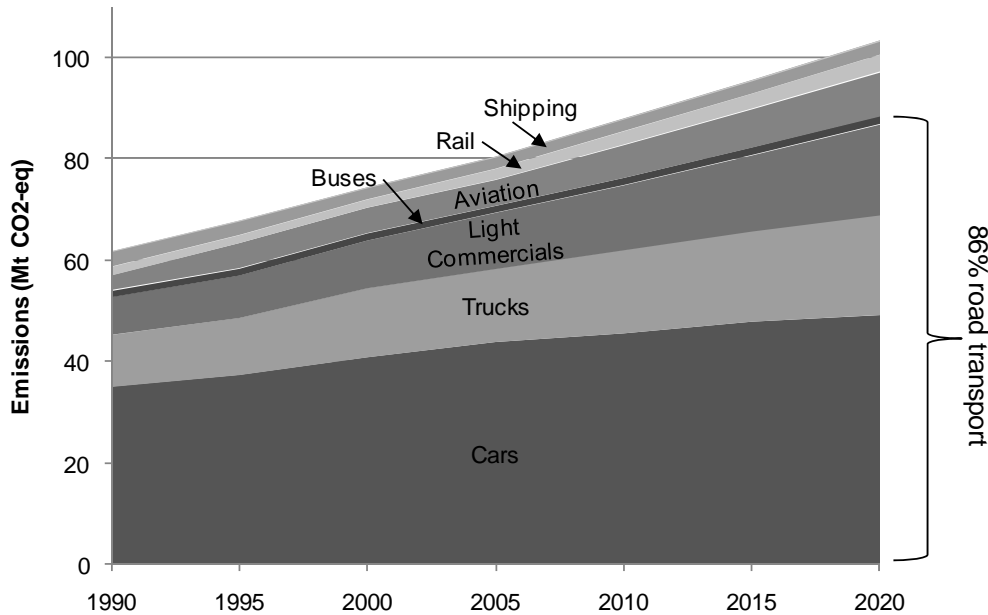


Figure 1: Australian Transport Emissions - actual and forecast (DCC 2008)

There are no published Australian projections of road transport GHG emissions to 2050 of which we are aware. We have projected 2050 emissions by extrapolating motor vehicle emissions growth trends in Department of Climate Change (2008) and Bureau of Transport and Regional Economics (2007a) beyond 2020 (with very modest allowance for further reduction initiatives). Our approach has been to take the annual traffic growth rate for each category of road transport vehicle over the forecast period to 2020 and extrapolate this to 2050, with a slightly slower growth rate (e.g. because of an ageing population and saturation in vehicle ownership), to produce “indicative” traffic volumes. Emission rates have been derived from these traffic flows by assuming emissions grow at around 80 percent of the rate of traffic growth, presuming a modest improvement in overall fuel economy performance.

Figure 2 sets out our indicative projection of Australian road transport GHG emissions to 2050, on these assumptions. With traffic growth on a “business as usual” basis and allowing for some modest measures to slow emissions growth, road transport emissions of 131 Mt CO₂-e are projected for 2050. To achieve a 2050 emissions target 80 percent below 2000 levels would require a reduction of almost 120 Mt CO₂-e in projected 2050 emissions.

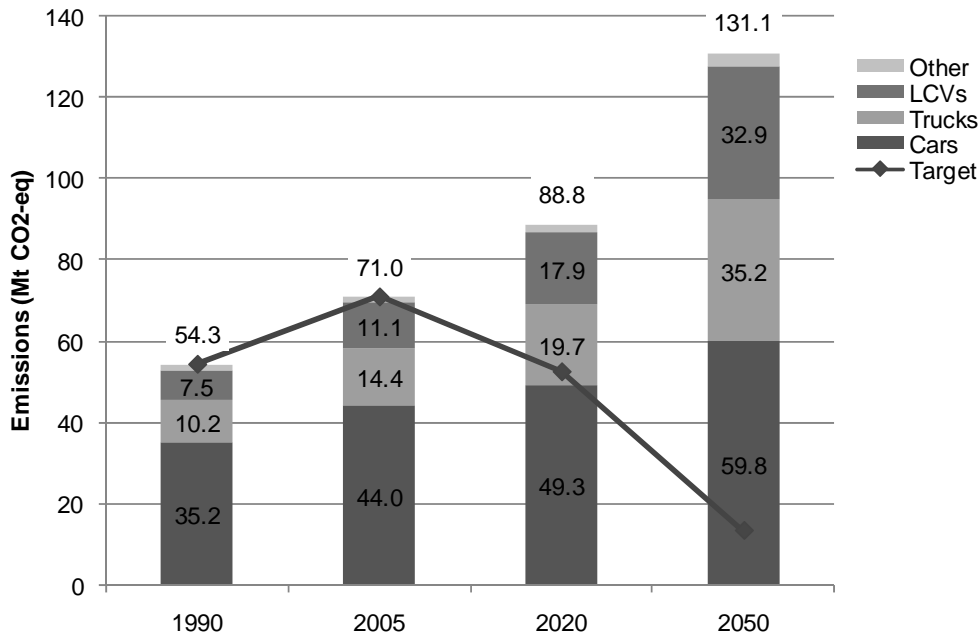


Figure 2: Actual and projected road transport greenhouse gas emissions compared to targets (2020=20 percent below 2000 and 2050=80 percent below 2000, totals shown in bold).

(Source: DCC (2008), BTRE (2007b) and authors' projections for 2050)

3. Meeting 2020 emission reduction targets

The paper considers six key ways by which road transport GHG emissions can be reduced to achieve the suggested 2020 emission reduction target of 20 percent below 2000 emission levels.

1. Reduce urban car kilometres travelled
2. Increase the share of urban trips performed by walking and cycling
3. Increase public transport's mode share of urban motorised trips
4. Increase urban car occupancy rates
5. Reduce forecast fuel use for road freight
6. Improve vehicle efficiency.

The following sections suggest indicative sub-targets for each of these actions, which will deliver the total emission reductions needed by 2020. These sub-targets are based on starting performance levels, achievements in other countries and likely Australian political and community support for implementation.

It should be noted that, in assessing the prospective impacts of these six measures, it has been assumed that each measure builds on those that precede it. Thus, for example, the impact of increasing the urban public transport mode share (measure 3) has been estimated assuming that the change in vehicle kilometres (measure 1) and change in walking and cycling (measure 2) have been implemented. This reduces the total road vehicle kilometres to which the higher public transport mode share has been applied, to estimate emissions savings. To this extent, some interaction between the various types of initiatives has been recognised but the impact assessments should generally be considered as first order and indicative.

3.1 Reduce forecast total urban car kilometres travelled

This first measure assumes reductions in urban car kilometres that are travelled in any year and that these reductions are not replaced by any other mode (i.e. the reductions represent overall reductions in total transport demand). While this measure is not a mode change measure in itself, it does impact on the consequential overall shares of each mode because the car task is reduced.. Specific mode changes are introduced separately as measures 2 and 3. It is assumed that reducing urban vehicle kilometres is likely to have less impact on traveller well-being if it is achieved by shortening trip lengths rather than by cutting out trips. Personal travel is the result of people undertaking activities at places that are separate to where they are located. The closer the desired activities are to the present location, the shorter the trip and the lower in general the emissions. Also, if various activities can be undertaken in a chained fashion, rather than with a return to base between each separate trip, travel distances can be reduced.

Given that most travel is undertaken by car, reductions in car kilometres is probably the single best proxy target for lowering emissions by shortening trip lengths and/or increasing trip chaining (see Bain et al 2008). Achieving reductions in car kilometres by such means partly requires the structure of cities to change, so that more people live closer to where they work and play. Most Australian capital cities are aiming to achieve more compact settlement patterns, but low density growth on the fringe is still the dominant pattern. Progress in implementing more compact urban settlement patterns needs to be accelerated, to help reverse emission trends.

A 10 percent reduction in urban car kilometres, from shorter trip lengths and greater trip chaining, deriving ultimately from more clustered urban activity patterns, would contribute about ten percent of the reduction target for 2020. Because of the connection between traffic levels, travel speeds, fuel consumption and GHG emissions, particularly in congested operating conditions, the reduction in emissions is not linearly correlated with reductions in traffic volumes. However, some related transport network modelling research undertaken by two of the current authors, on transport emission reduction policy options for Melbourne, has suggested that the assumption of linearity is a reasonable approximation. Relative emission reductions in that research, within the range considered in the present paper, were estimated to exceed relative reductions in vehicle kilometres of travel by only about one twentieth (Hensher et. al. 2008).

The subsequent discussion in Section 6 of the paper shows how, over the long term, urban structure can impact significantly on car usage. Travel behaviour change techniques can also have an impact on trip patterns (car trip rates and trip chaining), in the short term. This paper assumes the 10 percent figure as an indicative target to be achieved by 2020. The implications of this assumption are clear in table 1, so readers can explore the consequences of alternative assumptions.

3.2 Increase the share of urban trips by walking and cycling

A general strategy for reducing transport GHG emissions is to increase the relative task performed by low emission modes. There are no lower GHG emission modes than walking and cycling. Most Australian cities are well suited to cycling, with relatively friendly terrain. However, conflict with other road users, particularly cars and trucks, raises safety issues for cyclists. Provision of dedicated cycle paths/road space increases the safety of this form of travel.

Concerns about safety have contributed to a substantial shift in some forms of personal travel away from cycling to motor vehicles in recent decades, the trip to and from school being notable, as shown in Figure 3.² Given the timing of school trips, this shift increases congestion costs and adds GHG emissions at a high rate per kilometre travelled. This trend is not unique to Australia, being the same (for example) as is happening in the UK and Italy (Orsini and Viviani 2004). The trip to school is a prime example of short trips that are eminently suited to walking or cycling, being increasingly undertaken by car.

² Increasing female workforce participation over the period shown is also thought to have contributed to this changing mode split in Australia, with children being dropped at school by one or other partner on the way to work.

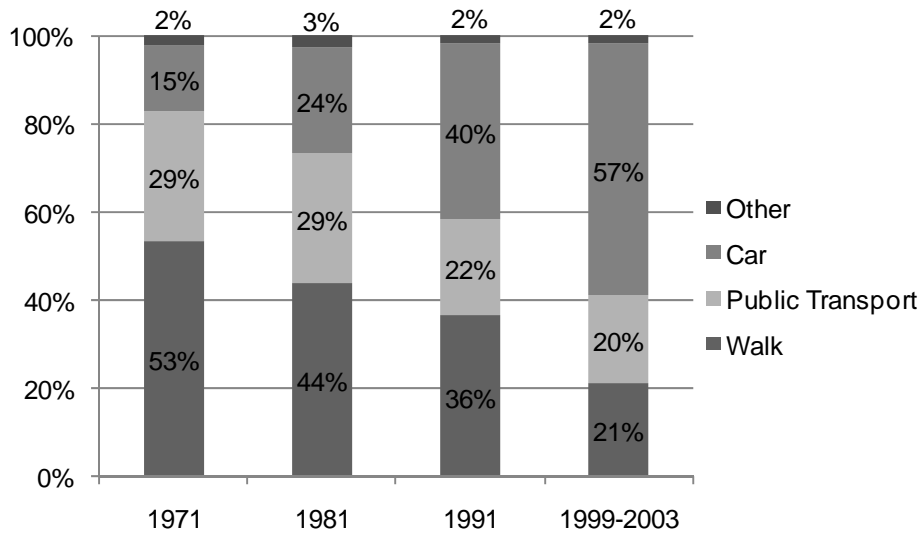


Figure 3: Method of travel to/from school in Sydney

(Source: van der Ploeg et al. 2008)

Overall, about 40 percent of trips in Melbourne are less than two kilometres in length, suited to walking or cycling, while another 22 percent are between two and five kilometres, well suited for cycling, provided suitable infrastructure is in place (Department of Transport 2008).

A target for one quarter of all trips in the major Australian cities to be undertaken by walking and cycling, compared to the current average share of around 16 percent, would contribute about 4.4 Mt of the targeted 36 Mt emission reductions at 2020. Such a change in travel patterns towards a more substantial role for more active modes would have an associated benefit of reduced obesity and improved health

3.3 Increase public transport's mode share of urban travel

Public transport (bus, tram, train, ferries) typically carries between about six and 13 percent of motorised trips in Australian cities (depending on the city). The Victorian State Government has adopted a target to raise this share to 20 percent by 2020 in Melbourne.³ While some commentators have dismissed this target as aspirational, Melbourne's public transport patronage is presently growing at around eight percent per year, which is about the rate required to achieve the 20 percent share. Strong public transport patronage growth is also being experienced in other Australian cities.

The prospects for a 20 percent mode share of motorised trips by 2020 (and for shorter trip lengths and increased walking and cycling, as per measures 1 and 2) would be enhanced if a comprehensive road pricing regime was to be introduced, including congestion charging. The intent would be to make road users accountable for the full costs of their travel choices (including GHG emissions, air pollution costs, road damage, noise costs, accident costs that are external to insurance cover and congestion costs). For example, road traffic levels dropped initially by about 20 percent in London in that city's congestion charging area⁴. Comprehensive road pricing schemes would produce much smaller impacts across the city as a whole than in the most congested locations. However, comprehensive road pricing would still be a significant driver of public transport use across a wide area.

³ The mode share was nine percent at the time this target was announced and has subsequently increased strongly to 13 percent.

⁴ See http://www.abd.org.uk/london_congestion_charge_report2007.htm Initiatives for bus and pedestrian priority traffic have tended to keep congestion levels high, suggesting that a fixed price regime may not be the best way to manage the road network.

Complemented by substantial improvements in public transport service levels, including on-road priority, a 20 percent mode share target by 2020 is not impossible, particularly if fuel prices remain high.

Hensher and Stanley (2008) have forecast the effect of higher fuel prices on car and public transport use in Melbourne. Assuming that petrol and diesel prices increase at the rate of \$A1 annually, they forecast a 20 percent reduction in passenger vehicle kilometres in 2013, with a larger proportionate reduction in emissions. By this time fuel prices were assumed to be \$6/L, about four times the current price but equivalent to a congestion charge of under 50c/km (high if applied city-wide but not high in congested periods/places). Under this pricing regime, public transport patronage more than doubles. At \$2/l, about one-third above mid-2008 prices, the effect is to reduce passenger vehicle kilometres by 6.5 percent and increase public transport patronage by over 15 percent.

Political will is central to reform of road pricing arrangements. While this will is not apparent in Australia at present, the rapidly growing interest in road pricing internationally suggests that it will figure prominently on the Australian reform agenda within the next 5-10 years (Hensher and Puckett 2007).

Doubling public transport's mode share at a time when total trip numbers are increasing means that the numbers of trips catered for by public transport needs to more than double by 2020. This will require a considerable improvement in infrastructure and services, supported by road pricing reform.

An increase in public transport mode share is not emissions free. Peak period utilisation of public transport is high. To minimise the impact of public transport patronage increase on emissions, peak-spreading strategies would be needed in the short term, until infrastructure expansion strategies can be implemented.

Achieving a 20 percent public transport modal share of urban motorised trips by 2020 (or around 15 percent of all trips) would contribute about seven percent of the targeted emission reduction to 2020. This is smaller than many public transport supporters would expect but it reflects the low starting mode share in Australia, with its low density settlement patterns.

3.4 Increase urban car occupancy rates

Car occupancy rates are typically low in Australia. For example, the average occupancy rate in Victoria is about 1.4. However, morning peak occupancy rates on Melbourne's freeways are just 1.14 on average (VicRoads 2007). With the high mode share performed by the car, increasing occupancy rates are a real opportunity to cut emissions, provided this is achieved by lowering the number of cars on the road. This should be a major focus of policy attention, with appropriate incentives. Because the car mode share is so high, a small increase in occupancy rates achieved through trip sharing delivers important emission reductions.

Transit lanes that give priority to high occupancy vehicles must become commonplace in our cities, to encourage ride sharing and greater use of public transport. Allowing cars with three or more people to travel in these lanes, or occasionally two or more, and ensuring that transit lanes achieve much faster travel times than remaining lanes, would provide an incentive to increase occupancy. Also, motoring associations should promote a campaign among their members to car share as a more usual practice, raising awareness of the greenhouse benefits of this practice.

If the average urban car occupancy rate across Australia was increased from its estimated current level of 1.4 to 1.6 persons per car, this would cut GHG emissions in 2020 by around three Mt. Table 1 shows that this is slightly larger than the contribution from doubling the urban public transport mode split. Higher increases in occupancy rates would, of course, deliver even larger savings. The increased occupancy rates must not be allowed to attract additional vehicles on to the road network, an effect that would dissipate the potential emissions savings.

3.5 Reduce forecast fuel use for road freight

Freight movements are projected by the Bureau of Transport and Regional Economics (2007b) to continue strong growth, doubling between 2000 and 2020. While road freight tonnes moved have been growing roughly in line with economic growth (Gross Domestic Product), road freight tonne-kilometres (tkms) have grown much faster than GDP, as shown in Figure 4. While some of this growth in tkms will be accounted for by longer travelling distances that are required in Australia's growing cities, it suggests there are opportunities to meet the same freight task more efficiently.

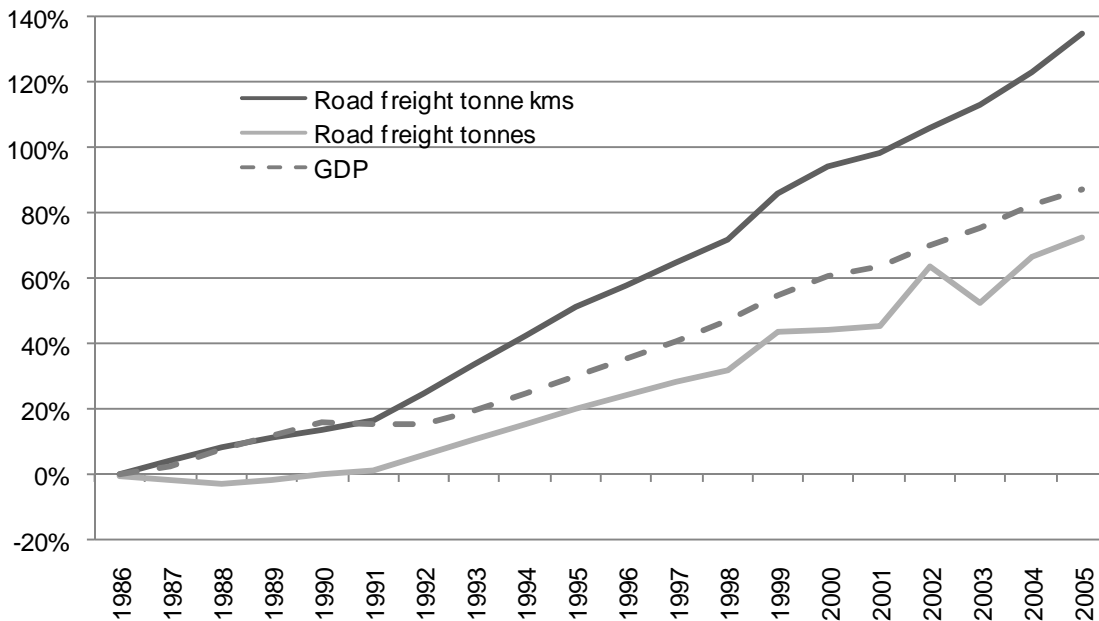


Figure 4: Growth in road freight tonnes, road freight tonne kms and GDP since 1986

Two major opportunities for reducing the growth in road freight tonne kilometres are improving the efficiency of truck movements and shifting greater volumes of freight onto rail.

Road freight efficiency can be improved in many ways. One important way is through use of higher capacity vehicles (e.g. B-triples⁵), utilising performance-based standards to extend access opportunities beyond what might otherwise be possible for such vehicles. Australia is a leader in terms of development of such vehicles and access regimes. Facilitating greater innovation in vehicle design, while developing infrastructure (e.g. bridges) that is more suited to higher payloads, is an important way to allow fewer, more efficient trucks on the roads, and reduce emissions on a per tonne-kilometre basis.

Higher utilisation of trucks through better scheduling would reduce the number of unproductive trips. Surveys of trucks operating around the Port of Melbourne show that, on average, half the container slots were empty, and 37 percent of container trucks carried no containers at all (PMC 2006). Increased back-loading, through more integrated scheduling, could increase truck utilisation, reducing emissions from unproductive trips. In addition, shifting freight traffic from congested peak periods to other times of the day would also result in lower emissions.

Fundamental to efficient resource use in transport is a pricing system that requires users to meet the marginal costs attributable to their travel decisions, as argued in Section 3.3 above. Road use in Australia currently lacks such a system. While the Australian road pricing system for trucks implemented by the Australian National Transport Commission is structured to charge heavy vehicles for their road damage costs, subject to some charge averaging provisions, other external costs of road

⁵ A prime mover with three trailers.

use are completely ignored by pricing systems. These external costs are particularly substantial in congested urban areas, which account for 50 percent of total truck kilometres and 62 percent of light commercial vehicle kilometres.

The Bus Industry Confederation (BIC 2001) estimated average external costs⁶ of articulated truck use in urban areas at 49-73c/l, excluding congestion costs. These costs would be considerably higher today. Congestion costs are the largest single external cost of urban road use and would more than double the 49-73c/l external costs of articulated truck use in peak periods. None of these external costs are charged to truck use, except for road damage costs.

To substantially cut transport emissions, rail must also play a much larger role in freight movements. Critical to achieving a larger role for rail is fast-tracking the establishment of inter-modal freight terminals in Australia's major cities, especially in relation to port and interstate freight movements. If external costs were charged for road use by trucks, more intermodal freight hubs would become financially viable and the rate of growth of road freight would reduce, as logistics processes are reviewed, with corresponding reductions in GHG emissions.

We assume sufficient improvements in truck productivity, scheduling and a mode shift to rail to deliver a 20 percent reduction in fuel use required to meet the forecast freight task, which translates to an emissions saving of 30 percent of the total sought in 2020. This emissions saving is made prior to efficiency improvements detailed below.

3.6 *Improve vehicle efficiency*

BTRE (2007a) suggests that the overall fuel intensity of Australian road transport has shown little change over the 1990 to 2006 period. For example, average fuel economy for cars has fallen a bare five percent since 1990. For light commercial vehicles, the reduction was even less. While engines are becoming technically more efficient, Australians are buying larger and heavier vehicles, offsetting the potential fuel savings. Many governments continue to add six cylinder vehicles to their fleets. Australia's emissions targets for new vehicles are still well above those adopted by Japan, China and Europe.

In framing this initial set of options, the chosen approach has been to use vehicle fuel efficiency as the "gap filler", between the overall reduction target that is being sought and the cumulative contribution from the preceding five initiatives. A 30 percent reduction in average car fuel economy, and an 18 percent reduction in average freight vehicle fuel economy, would contribute about one third of the total emission reductions that are needed. For cars, the fleet emissions intensity would need to drop from the current average of 220 g/km (11.4 l/100km) to around 151 g/km by 2020 (or 8.1 l/100km) to provide a 30 percent reduction. In view of the aggregate performance cited above for the 1990 to 2006 period, mandatory fuel efficiency standards are likely to be needed to deliver this outcome.

Alternative fuels such as gas and biofuels can contribute to lower overall road transport GHG emissions and their use is expected to grow, especially second generation biofuels (where food security is less of a concern than with some current sources). It is a matter for government policy choice how encouragement of such options is balanced with broad regulatory tools like mandatory emissions standards, which themselves help drive the search for alternative fuels by setting the framework within which the market seeks complying solutions.

3.7 *Overall impact*

Option A in table 1 shows how the six components considered above combine to deliver the 36 Mt CO₂-e total reduction that is being sought.⁷

⁶ These costs included road damage, noise, air pollution and the costs of road accidents not covered by insurance.

⁷ In Table 1, a truck is defined as a motor vehicle exceeding 3.5 tonnes mass, constructed with a load carrying area. A light commercial vehicle includes rigid trucks of less than 3.5 tonnes, utilities, panel vans and vans without rear seats.

Table 1: Emissions savings (from forecast) from further reduction measures to achieve a 20 percent reduction on 2000 levels by 2020: three options

Measure	Target	2007	Option A			Option B	Option C
			2020	Emissions saved (Mt)	Share of savings	2020	2020
1. Fewer/shorter urban car trips	Less car kms	-	10%	3.5	9.2%	20%	25%
2. Shift urban car to walking/cycling	Active transport mode share (urban)	16%	26%	4.4	11.6%	34%	39%
3. Increase urban public transport mode share	PT mode share (all urban trips)	7.5%	15%*	2.6	7.0%	20%	21%
4. Increase urban car occupancy	Passengers/car	1.4	1.6	3.0	8.0%	1.8	1.9
5. Freight efficiency	Less fuel than forecast	-	30%	11.7	30.9%	30%	30%
6. Car Emissions intensity	Less than 2007	-	30%	8.2	21.8%	18%	13%
Truck emissions intensity	Less than 2007		18%	4.4	11.5%	13%	8%

Note: * The 15 percent mode share is 15 percent of all trips, which is equivalent to 20 percent of motorised trips.

These measures rely heavily on car and truck fuel efficiency improvements, which provide a third of the total emissions savings. The sheer size of the Australian vehicle fleet, and its relatively poor economy record, means improvements in fuel efficiency have the greatest potential impact on emissions.

Behaviour change in favour of purchasing more fuel efficient vehicles can assist the achievement of emissions reductions, but tough mandatory emission standards will probably be required to drive these reductions, making the issue much less one of consumer choice about the fuel economy performance of the vehicles they choose to purchase than about the regulatory environment within which such choices take place.

Table 1 is considered a feasible combination of measures that would deliver the target emission reductions by 2020. However, other possible combinations could deliver the same result, as shown by Options B and C in table 1, these alternative options highlighting some of the choices that will need to be confronted by governments and the wider community.

Table 1 shows that, if significant improvements in fuel efficiency are not achieved, very significant changes in travel behaviour (walking, cycling and use of public transport) are required to make up the shortfall. Options B and C rely on much greater travel demand reduction and mode shift to walking, cycling and public transport (car mode share is reduced from 77 percent to 48 percent in option B, and 40 percent in option C). This highlights the critical importance of achieving fuel efficiency targets, and the urgency of an early start, given the time lags in new emission standards filtering through the fleet.

On the other hand, if fuel efficiency was to be the only method of emissions reduction, emissions intensity cuts of 54 percent for cars and 37 percent for trucks (as an example) would be required over the entire fleet by 2020. Such large cuts would be extremely challenging, given that a significant proportion of the current fleet will still be on the roads in 2020. This highlights the equally critical importance of travel behaviour changes for reducing emissions.

4. Emissions trading/carbon pricing

Australia is planning an emissions trading scheme (called a Carbon Pollution Reduction Scheme) as the centre-piece of its approach to cutting GHG emissions (Australian Government 2008). How far might this go, on its own, to deliver the scale of emission reductions considered in this report?

Australian travel, both passenger and freight, is highly road-dependent. Fuel costs are a small proportion of the costs of such travel, with time costs typically being far more significant. As a consequence, the elasticity of demand for road travel with respect to changes in fuel prices tends to be low. Various studies of fuel price elasticities put short run values as low as -0.1 but long term values of the order of -0.6 to -0.7 are cited for petrol use by several sources (e.g. Goodwin et al 2003; Hagler Bailly 1999, Zheng et al. 2008), including an Australian study by the then Bureau of Transport Economics (BTE 1991). Diesel use elasticities are typically lower, with Hagler Bailly (1999) citing values of around -0.4.

We have assumed long run elasticities for fuel use of -0.7, to suggest how carbon pricing might impact on fuel use and consequential GHG emissions. A carbon price of \$A60/t is used in this assessment, since this figure is sometimes quoted as the level at which carbon sequestration might become economically viable, a key determinant of the path that Australia is likely to take to emissions reduction (given its high dependence on coal for electricity generation and the importance of stationary energy as a source of Australian emissions). Also, McKinsey (2008) has recently estimated \$A65/t as the marginal cost of reducing emissions in 2020 to 30 percent below 1990 levels. \$A60/t carbon price would add about \$0.17/l to the price of petrol, a 12 percent increase on prices of about \$1.40/l.

Applying an elasticity of -0.7 suggests a reduction in fuel use of only eight percent, which is nowhere near enough against the GHG emission reduction targets considered in this paper. For example, the achievement of 2020 emission levels 20 percent below 2000 levels requires an emission reduction of about 40 percent on projected emissions in that year. Much stronger interventions will be required to complement emissions trading, including investment in improved public transport services and infrastructure, urban design initiatives to facilitate greater walking and cycling, road pricing reform and regulatory change to facilitate emission reductions (e.g. mandatory fuel economy standards), as considered above.

5. Meeting 2050 reduction targets

To shed light on what might be needed to cut GHG emissions from Australian road transport by 80 percent on 2000 levels by 2050, a few broad scenarios have been developed. Compared to the 2020 options that were presented, the 2050 variants impose much tougher restrictions. Because of the critical role of vehicle emissions in driving total road transport GHG emissions, three scenarios have been developed which vary in the degree of fuel efficiency improvement delivered by 2050. These scenarios are labelled in Table 2 as “extreme efficiency”, “very high efficiency” and “high efficiency”.

**Table 2: Road transport emission reduction scenarios that achieve an 80 percent cut
below 2000 levels by 2050.**

Measure	Target	2007	2020 (option A)	2050 Extreme efficiency	2050 Very high efficiency	2050 High efficiency
1. Fewer/shorter urban car trips	Less car kms	-	10%	10%	25%	30%
2. Shift urban car to walking/cycling	Active transport mode share (urban)	16%	26%	29%	45%	53%
3. Increase urban public transport mode share	PT mode share (all urban trips)	7.5%	15%	16%	33%	38%
Car mode share	(urban trips)	77%	59%	57%	23%	11%
4. Increase urban car occupancy	Passengers/car	1.4	1.6	1.7	2.6	2.8
5. Freight efficiency	Less fuel than forecast	-	30%	30%	60%	80%
6. Car emissions intensity	Less than 2007	-	30%	92%	84%	75%
	g/km	220	155	18	36	54
Truck emissions intensity	Less than 2007		18%	89%	83%	75%

Source: Authors projections.

The 80 percent target, not surprisingly, poses some very tough questions in terms of the future role to be played by cars and trucks. Its achievement depends heavily on very major cuts being delivered in the emission intensity of the motor vehicle fleet (about 90 percent improvement per unit travelled for Australia's case). Anything less than this and there is a clear incompatibility between the traffic projections and emissions targets. That incompatibility can only be resolved by

- significantly changing travel behaviour to increase the role of low carbon modes, and/or
- lowering the emission reduction target for the transport sector, which increases the burden to be taken up by other sectors.

Table 2 shows three varying rates of improvement in car and truck emission intensity. Slightly greater improvements are included for cars than for trucks, because the Australian car fleet is relatively higher in emission intensity, compared to overseas cars, than the truck fleet, which relies on imported chassis. This creates greater relative opportunities for improving car emissions (e.g. by importing more fuel efficient overseas models if they are not available locally).

The "extreme efficiency" scenario, which embodies assumptions of 92 percent improvement in car emissions performance and 89 percent in truck performance over 2007, does not require huge relative gains in public transport mode share or in walking/cycling or reduced travel, beyond the targets set for 2020, to achieve the 80 percent sectoral target. However, the other two scenarios show that any percentage point shortfall on emissions intensity achievement in the vehicle fleet requires very large gains in the other initiative areas if the 80 percent reduction is to be anything more than a dream. For example, with a still substantial 75 percent improvement in car and truck emissions performance by 2050 (the "high efficiency" scenario), achieving the overall 80 percent target requires huge increases in public transport mode share, car occupancy rates, freight efficiency, the mode share of walking and cycling and large reductions in travel distances. All the scenarios are consistent with Australian cities that are much more compact than today, with the "high efficiency" scenario requiring the greatest increases in density to be achievable.

The 2050 target sets a clear challenge for Australia's road transport sector and for road transport in other developed countries with low density settlement patterns. Massive technological change and equally massive change in travel behaviour, and the drivers thereof, are in prospect, or else the road transport sector will depend significantly on others to pick up what might be regarded as its responsibilities to clean up its greenhouse act!

6. Urban structure and transport greenhouse gas emissions

Many of the initiatives considered in this paper will benefit from urban development policies and plans that facilitate more compact urban settlement patterns. Such urban design will help to reduce travel distances (e.g. because of closer proximity of trip origins and destinations), make walking and cycling easier and improve the economics of public transport service provision.

An illuminating example of how urban development patterns and associated public transport service provision influence travel patterns is presented by Bento et al. (2005). They examined the effects of urban form and public transport supply on travel mode choices and annual vehicle travel in 114 US cities. Population centrality, the jobs-housing balance, city shape and density were found to have a significant effect on the amount of vehicle travel. They illustrate this connection by pointing out that the effect of moving a sample of households from a city with measures of urban form and transit supply the same as those of Atlanta (733 persons per km²; 7000 rail miles of service/km²; 10,000 bus miles of service/km²) to a city with the characteristics of Boston (1202 persons/km²; 18,000 rail miles of service/km²; 13000 bus miles of service/km²) reduces annual vehicle travel by 25 percent (from 16,899 miles per household per annum to 12,704). It reduces the probability of driving to work from 0.87 to 0.73, a very substantial drop. They point out that this reduction is driven by differences in public transport supply, city shape and especially in population centrality (essentially compactness).

While individual factors have only small impacts in the analysis by Bento et al., the joint impact of the various factors is significant, emphasising the importance of taking an integrated and systemic approach to reducing transport GHG emissions, including both land use and transport elements. While urban structure only changes slowly, long term approaches must be taken to deliver substantial emission cuts and this will require land use to play a central role.

More compact urban form can contribute to emission reductions in several of the six key areas outlined in this paper, from reducing necessary trip lengths to increasing the effectiveness and attractiveness of public transport, walking and cycling for person movement and of rail and intermodal hubs for freight movement. Policy approaches that pursue an integrated approach to land use and transport are likely to achieve greater emission reductions than approaches that ignore these linkages.

7. Equity implications

Research by the National Institute of Economic and Industry Research (2007) for the Brotherhood of St Laurence (a major Australian welfare organisation) has demonstrated that carbon pricing regimes will have regressive distributional impacts. A relatively high reliance on car travel, and the impact of carbon pricing (or emissions trading) on fuel costs, is one way in which this regressive impact emerges. This effect would be further compounded if externality-based pricing mechanisms were implemented (as proposed in this paper) to reform charging for road use, since these measures are prospectively regressive.

A number of the complementary measures considered in this paper can mitigate the regressive distributional impacts of carbon pricing and of road pricing reform. Both reformed road pricing arrangements and emissions trading schemes can generate very substantial revenue flows to government. Targeting use of some of this revenue to mitigate adverse distributional consequences for disadvantaged people provides an important means of combating these impacts. The Australian Government's Carbon Pollution Reduction Scheme for example, proposes substantial compensation to low (and middle) income households who are expected to be adversely impacted by emissions trading (Australian Government 2008). This generic compensation can be complemented by place-based targeting of measures (such as public transport services) that aim to improve mobility opportunities for disadvantaged people. For example, improved public transport services can be targeted, inter alia, at areas where low income people are highly represented, if current services are relatively poor. This is the case in Australian outer urban and regional areas, where the impact of an emissions trading scheme on disadvantaged people is expected to be highest (Unkles and Stanley 2008).

Urban design that provides greater opportunity for walking and cycling can also improve the opportunities available for low income people. This opportunity can be further enhanced by inclusion of affordable housing in areas where development densities are being increased. Careful use of the revenue streams from emissions trading and road pricing reform thus provide a key to mitigation of adverse equity consequences of measures to reduce GHG emissions. They also open the possibility for more positive discrimination if the political will exists.

8. Conclusions

Australia's road transport sector is a major contributor to the nation's GHG emissions and road transport emissions are growing rapidly. Achieving major reductions in GHG emissions from the road transport sector must therefore be a central part of any national effort to cut emissions.

A national emissions trading scheme is a central part of Australia's response to combating climate change. However, this analysis suggests that an emissions trading scheme by itself will only slow the rate of growth of road transport GHG emissions. Achieving reductions in road transport GHG emissions will require a much broader policy response.

Reducing road transport GHG emissions will require step changes in the conditions underlying personal and freight mode choices and in fuel efficiencies. The analysis suggests that a multi-faceted approach to cutting road transport GHG emissions will be needed. Behavioural change will lead in the short term and technological change must follow close behind, with the rate of improvements that are achieved in vehicle emission intensity being the single largest driver of what is possible. Poor performance in this area means drastic changes in travel behaviour to achieve the same total impact.

There are nine key areas which can help to drive the emission reductions that will be needed, to complement gains from an emissions trading scheme. These are:

1. Comprehensive road pricing, including congestion charging
2. Increased investment in public transport facilities and services
3. Major investment in facilities to encourage walking and cycling
4. More compact, walkable urban settlements
5. Significantly improved fuel efficiency (mandatory targets)
6. Investment in rail freight and intermodal hubs
7. Freight efficiency improvements (e.g. more productive vehicles; changed delivery times)
8. Reallocation of road space to prioritise low emission modes (including high occupancy vehicles)
9. Behaviour change programs to encourage car sharing and use of low emission modes.

Governments could simply decide to increase fuel taxation to reduce the demand for road travel and cut GHG emissions. However, the present authors believe that a charging system which reflects all the external costs of road use is the most economically efficient way to reform charging for the use of roads, recognising that there are many issues other than GHG emissions that need to be considered in setting such charges (e.g. congestion, road damage costs, accident costs, air pollution, noise, etc). By seeking to make all these considerations explicit, externality-based charging should help to ensure that resource allocation in the road transport sector more generally is improved. There will, of course, be implications for fuel taxation in how such a system is delivered but the approach has a broader and more solid theoretical basis than simply linking fuel taxes to an objective of cutting GHG emissions.

Implementing the wide range of policy initiatives that will be required to cut road transport GHG emissions will not be cheap. However, the benefits of these initiatives will range far wider than just GHG benefits. They will include very substantial benefits from:

- cutting road congestion costs
- lowering air pollution levels and reducing traffic noise
- cutting accident costs
- increasing social inclusion and, very importantly,
- improving the liveability of communities.

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