Australian Car Travel: An Uncertain Future

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1 Introduction

For many decades, car travel has been accompanied by problems of traffic congestion, traffic casualties and air pollution, particularly in our large cities. Traffic congestion has not hindered the growth of automobilisation in Australia: ownership of passenger cars has risen from around 75 per 1000 persons in 1947 to 545 in 2006. Light vehicles (passenger cars plus light commercial vehicles) in 2006 numbered 645 per 1000 (Australian Bureau of Statistics (ABS) 2006a, 2007). Despite the huge rise in car numbers and travel, traffic fatalities have fallen from their peak of 3798 in 1970 down to 1636 in 2005 (ABS 2007), in response to a variety of measures that include compulsory seat belts and changes to vehicle design. Vehicle air pollution emissions are also being succcessfully tackled by technical solutions such as legislation for unleaded petrol, three-way catalytic converters and low-sulphur fuels.

Two more recent major challenges to Australian automobility are global climate change from greenhouse gas emissions and depletion of Australian and global oil reserves. Many researchers advocate approaches similar to those used with some success for traffic casualty and air pollution amelioration for overcoming these challenges as well. Some have argued that both problems can be solved with a combination of two key technical solutions—large improvements in vehicle fuel efficiency and a switch to alternative transport fuels, such as liquid biofuels and hydrogen derived from renewable energy. (e.g. Lovins 2005, Turton 2006).

The aim of this paper is to show that continued private car travel cannot form the basis for a sustainable Australian system of surface passenger travel. We argue that the risks of global climate change and oil depletion, both Australian and global, require effective reductions in the next two decades or so, whereas technical solutions to drastically cut car travel's greenhouse gas emissions and oil consumption are only possible in a much longer time frame, and possibly not even then. Overall, Australia will have to rely on alternative modes (various forms of public transport, walking and cycling), and much-reduced levels of personal travel as well.

2 Sustainability challenges to car travel

2.1 Global climate change

The climate change debate is rapidly changing; increasingly the question is not whether humans are influencing climate but what actions need to be undertaken. The vast majority of climate scientists support the view that emissions of heat-trapping gases into the atmosphere, particularly CO_2, from fossil fuel combustion and land-use changes, cause global warming by altering the Earth's radiation balance. The 2007 report from the Intergovernmental Panel on Climate Change (IPCC) states that sea levels are rising, glaciers and sea ice cover are diminishing, and that 11 of the 12 warmest years since 1850 have occurred in the 1995-2006 period. Their latest estimate (with a probability of 66 % or greater) for climate sensitivity—the equilibrium increase in global temperature resulting from a doubling of CO_2 in the atmosphere—is from 2.0 ºC to 4.5 ºC, with a best estimate of 3.0 ºC (Solomon et al 2007). Atmospheric CO_2 concentrations have passed 380 parts per million (ppm) and are currently rising by some two ppm annually.

The European Union (EU) has set a maximum rise of 2 ºC above preindustrial levels to be reasonably sure of avoiding dangerous climatic change. To keep below this target, some researchers (den Elzen et al 2006, den Elzen and Meinshausen 2006) calculate that for a climate sensitivity of 3.0 ºC, world CO_2-equivalent ($CO_{2\text{-e}}$) emissions need to be capped at levels as low as 400 ppm. Since non-CO_2 greenhouse gases are now roughly equivalent to 50-100 ppm CO_2, the world has already passed the 400 ppm $CO_{2\text{-e}}$ level. The need for prompt reductions is evident, even if overshooting is unavoidable in the short-term. Evidently, many different reduction paths will produce a given future reduced $CO_{2\text{-e}}$ level. But earlier action pathways can 'profit from induced technology and an earlier signal of change to the energy system (and thus a more gradual response)' (den Elzen et al 2006). Delaying effective response may be politically easier, but it will entail higher overall costs and more eventual disruption. Reductions will prove progressively more difficult as the industrialising countries also get locked into high fossil fuel consumption patterns.

Moreover, large positive feedback effects could result in emissions, and thus temperatures, rising much more rapidly than expected on the basis of present trends. One such feedback is large-scale methane release from northern tundra as permafrost melts. There is some preliminary evidence that this process is already underway (Leggett 2006, Overpeck et al 2006). Further, studies of past climate has shown that abrupt climatic change can occur over the course of a decade or even a few years (Overpeck and Cole 2006). James Hansen, a prominent US climate scientist, has argued on the basis of paleoclimatic data that if further global warming is not limited to 1 ºC beyond the year 2000 value (slightly below the EU value of 2 ºC above the pre-industrial value), feedbacks could add to business-as-usual emissions, making the world a 'different planet' (Hansen et al 2006). He concludes that we can only continue present trends for GHG emissions for another decade or so before committing the climate to irreversible change (Hansen et al 2006). Here, we take a position intermediate between den Elzen/Meinshausen and Hansen, and assume that by 2030 global emissions of both CO_2 and other GHGs must be reduced to 25 % their current value—a fourfold reduction in current global emissions.

Thus, to limit dangerous climatic change, annual emissions to the atmosphere of CO_2 and other greenhouse gases will need to be greatly curtailed, unless geo-engineering or carbon sequestration techniques (discussed below) can be successfully deployed in time. Equal emissions per capita for all countries, as advocated by the 'contraction and convergence' proposal (Bow and Anderson 2006), is likely to be the only acceptable policy, since it is improbable that industrialising countries such as China or India will permanently accept lower per capita emissions than the already-industrialised countries. In 2002, global $CO_{2\text{-e}}$ emissions (excluding only those from land use change) averaged 5.4 tonnes/capita (World Bank 2006), but varied widely from country to country. Australian emissions at 25.2 tonnes/capita were 4.7 times larger than the world average, implying a reduction factor of 18.8.

2.2 Australian and global oil depletion

Much controversy exists as to whether or not the world will soon face a global oil crisis. In the following discussion, 'oil' includes both conventional and non-conventional oil (heavy, polar, deep-water, natural gas liquids).The US Energy Information Administration (EIA) projects that world demand for (and production of) oil in 2030 will be 118 million barrels per day (mbd) compared with around 82 mbd in 2005 (BP 2007, EIA 2007). In total contrast, the Association for the Study of Peak Oil and Gas (ASPO)—whose key members are retired petroleum geologists—argues that 2030 production will be only about 63 mbd, and that oil production could peak as early as 2011—only four years away (ASPO 2007).

They can't both be right. The EIA figure is perhaps best interpreted as what the world would like to consume in 2030 if there were no constraints on oil supply. After falling during the 1980s, world oil demand is once again growing rapidly, with industrialising Asian countries—particularly China—responsible for most of the growth. China today is the world's second largest importer of oil, but even so its 2006 annual per capita consumption of about 0.265 barrels is still less than 10% of that of the US, the leading importer (BP 2007).

What about the oil situation in Australia? For several decades we have enjoyed near net self-sufficiency, but this is set to change rapidly in the coming years. Geoscience Australia (Petrie et al 2005) project that production of crude petroleum plus condensate will have a 50 % chance of exceeding 0.239 mbd and a 90 % of exceeding 0.157 mbd by 2025. LPG production (0.082 mbd in 2005) must be added to these figures, but annual LPG production depends mainly on NG production, the main source. Meanwhile, oil consumption is still growing, and in 2005 was 0.884 mbd. Australian production of oil in 2005 was 0.554 mbd, down from 0.809 mbd in 2000 (BP2006). Clearly, Australia's steep decline in local production will co-incide with both rising aspirations for increased oil use by industrialising countries (and also Australia (Bureau of Transport and Resource Economics BTRE 2005)) and declining global availability.

Globally, new oil-field capacity must be brought on line each year, not only to meet rising demand, but also to cover depletion from older fields. Production capacity is what counts for oil availability, not the total oil reserves remaining, which for OPEC anyway are the subject of considerable uncertainty (ASPO 2007, Campbell 2006). It's the size of the 'pipe' that's important, not the size of the 'tank' This 'pipe' includes not only the annual production capacity of the world's oil fields, but also the capacity of pipelines and tankers that move it to domestic or overseas refineries, and the output capacities of the refineries themselves. All must expand together if the growing demand for petroleum products is to be met.

There is increasing evidence that the oil pessimists may be closer to the truth. Oil prices remain high, and will probably continue to do so unless a world recession lowers oil demand. Also, the annual additions to proven oil reserves continue to fall further and further behind annual consumption, and are now only about one-third of global annual oil use. Kuwaiti officials have acknowledged that their oil reserves are less than half the official value (ASPO 2007). Finally, the discussion is usually framed solely in terms of what oil importers want. But for many countries in OPEC, oil is their only exportable resource. It makes sense for them to keep production at levels which will ensure that oil production continues well into the future, both for their own needs and for foreign exchange earnings. Limiting production today maintains high oil prices, allowing given revenue needs to be met with lower production. Perhaps even we Australians could also leave some of our oil for our future generations.

2.3 Discussion

Much of the discussion on oil has focussed on how large the total extractable reserves base was, and what reserves remain. Similar questions about 'reserves' can be asked of CO_2

emissions. Broecker (2007) has introduced the notion of a 'carbon pie'.He points out that for each four gigatonnes (Gt) of fossil carbon burnt and emitted as CO_2, the atmospheric CO_2 concentration rises by one part per million (ppm). This '4 to 1' ratio will change only slowly over timescales of human interest (the 21st century), so that once we fix an upper level of atmospheric CO_2 ppm, we also fix the amount of carbon that can be released—from both fossil fuels and deforestation. Say, for example, we decide to fix the limit at 450 ppm CO_2, which, from the above discussion, may be too high. Then total carbon releases must be limited to 280 Gt, since present CO_2 concentration is about 380 ppm, leaving (450-380) x 4 = 280 Gt.

Since Australia has 0.31 % of the 2005 world population, our share would be about 870 Mt. The carbon content of our 2005 fossil fuel consumption was nearly 98 Mt (BP 2006, IEA 2006). Our entire remaining quota of carbon would be consumed in under nine years at present fossil fuel usage rates. If passenger transport is required to make percentage cuts in emissions similar to those in the economy overall, then clearly deep cuts are needed quickly. The next two sections examine whether such reductions are possible in the requisite time frame.

3 Solutions: more passenger-km per unit of fuel energy

Getting more passenger-km (p-km) per MJ of transport fuel is often seen as a key means of ameliorating Australian and global oil depletion/supply security. Greenhouse gas emissions will also be reduced by the same factor as petroleum fuel reductions. Passenger-km/MJ is the product of the following two factors:

- The vehicle occupancy rate (p-km/vehicle (v)-km)
- The vehicular well-to-wheels (i.e. primary) energy efficiency (v-km/MJ)

The following sub-sections examine the potential for raising occupancy rates and fuel efficiency. In such analyses, it is important to distinguish between, on the one hand, voluntary change, or politically feasible mandated changes under normal conditions, and on the other, changes due to what climatologists in a different context term 'external forcing'—for example changes brought about by declining global oil production, or by governments being required to meet serious GHG reduction targets.

3.1 Improving occupancy rates

An important advantage of improving vehicle occupancy is that in principle it can be implemented very rapidly with the existing vehicle fleet. The potential efficiency gains are also large. Historically, occupants per car in Australia have steadily fallen; it has not been possible to maintain, let alone raise, occupancy in the face of continued increases in both incomes and car ownership, and declining household size. For the journey to work trip in Melbourne, occupancy fell from 1.37 in 1951 to 1.08 in 2001, and was highly correlated with car ownership (Moriarty and Mees 2006). Nationally, car occupancy for all trip types has declined in a similar manner (Moriarty 1997).

Programs to encourage car-pooling in Australia (and other western countries) have met with little success at the national level, as witnessed by the steady decline in occupancy rates. Motorists presently seem reluctant to share their vehicle with non-family members—understandably, given different tastes in music, degree of driving caution, and standards of punctuality. All these differences dampen enthusiasm for car-pooling, at least when car ownership is high and car travel costs low.

However, Noland, Cowart and Fulton (2006) have recently argued that major occupancy changes could be expected under emergency conditions, such as a fuel strike. But what if the emergency is endless, rather than lasting for only a week or so? In that case, motorists could expect no return to normal conditions. If car occupancies were permanently required to double to around, say, three persons per car, the nature of car travel, and its perceived benefits, would be profoundly changed. Timing and even destination of trips would have to be negotiated to fit in with the needs of others, often non-family members. In many cases, trips would have to be made in which the driver merely chauffered family or non-family passengers to their destinations. In such cases, the car is used as a taxi, and like other forms of public transport, the driver should be discounted as an occupant. The apparent increase in occupancy would then be largely illusory from an energy-saving viewpoint.

3.2 Improving fuel efficiency

Like raising car occupancy, improving energy efficiency is often seen as a means of addressing both greenhouse gas emissions and Australian and global oil depletion/supply security. However, to date, progress in improving fuel efficiency of Australian passenger cars has been disappointing. Fuel efficiency of road vehicles has been measured by ABS surveys since 1963, but there are doubts about their accuracy until recently (Moriarty and Mees 2006). Independent surveys are available for 1985 and 1995 (Dynamic Transport Management 1997), as well as reliable 2005 ABS data (ABS 2006b). These show fuel efficiencies of 8.3, 9.1 and 8.5 v-km/litre for 1985, 1995 and 2005 respectively. Clearly, improvements in fuel efficiency will be minor under ‘business as usual’ conditions. This conclusion is supported by the BTRE (2005), who project only an 9.1 % rise in fuel efficiency from 2004 to 2020 in their base case.

Two general approaches are possible for improving energy efficiency. The first is to decrease the ‘road load’—the sum of rolling, inertial, and air resistance. Reducing the mass of the vehicle by further use of lighter-weight materials is the most important means of decreasing the road load. The second is to raise the share of input energy driving the wheels. Electric drive is today regarded as the best approach for achieving this aim. A variety of possible vehicle types have electric drive, including hydrogen fuel-celled vehicles, pure battery electric vehicles, hybrid electric vehicles, and recently, plug-in hybrid electric vehicles. Here we discuss only conventionally-fuelled vehicles. Compared with an equivalent conventional petrol-engine car, full hybrids can reportedly improve fuel efficiency by up to 60 %, with the higher gains made for urban driving. Hybrid efficiency gains come not only from regenerative braking and idling elimination, but also because the smaller conventional engine can run closer to full-load conditions (Romm and Frank 2006).

There is thus ample scope for efficiency improvements in conventionally-fuelled vehicles, given strong motivation. After reviewing the literature, the present authors concluded that by 2030 it would be possible to raise the ‘tank-to-wheel’ energy efficiency of the light vehicle fleet by a factor of 2-2.5, assuming that we began now (Moriarty and Honnery 2007a). But at present, there is little sign of progress in Australian car fleet efficiency. Offsetting this potential gain will be the steadily declining ‘well-to-tank’ efficiency. Cleveland (2005) in his study of US oil extraction found that the energy costs of finding and producing a barrel of oil had risen by a factor of five since 1930. Enhanced oil recovery (secondary and tertiary) is a major factor in increasing energy costs, as is also increased use of non-conventional oils like the heavy oils of Venezuela. For the ‘tar sands’ of Canada, the energy for a litre of petrol is much higher than for petrol from conventional oil (Soderbergh, Robelius and Aleklett 2006). Energy costs would be even higher if Australia's considerable resources of shale oil are ever developed.

Cars are different from other energy-using devices, such as refrigerators or washing machines, in that both car ownership and operation confer considerable psychological benefits (Moriarty and Honnery 2005, Ory and Mokhtarian 2005, Urry 2006). Further, again unlike these domestic appliances, people don't merely use but actually *occupy* their vehicles—for several hours per day on average. Motorists therefore regard not only fuel efficiency, but also vehicle comfort, reliability, security, safety, space provision and carrying capacity as important. The result is that much of the gains already achieved in engine efficiency in Australia have been offset by heavier and higher-performance vehicles, and rising energy use for vehicle air-conditioning, power steering, entertainment, safety and information systems.

The above analysis has assumed levels of vehicle performance, comfort, occupant space provision, and carrying capacity at least equal to those of today's mid-sized sedans. What if these levels were much reduced in an attempt to achieve transport sustainability? The authors have calculated the energy efficiency improvements possible with 'slower, smaller and lighter urban cars' on the Sydney driving cycle (Moriarty and Honnery 1999). They found that much higher energy efficiencies than those discussed above were possible even with non-hybrid cars, of, for example, 300 kg mass and maximum speed 50 or even 30 km/h. But it is doubtful whether motorists would be prepared to disregard nearly all of the perceived benefits of car travel for the sake of higher fuel efficiency. Further, a maximum car speed of only 30 km/h could tip the balance of travel times in favour of public transport.

4 Solutions: use of alternative fuels

One way around the difficulty of raising vehicle efficiency is to move away from petroleum-based fuels to alternative fuels. Using alternative fuels, usually with new power systems, will always lower oil consumption, since non-transport uses for oil in Australia are minor. For example, since oil generates less than 1 % of Australian electricity, (World Bank 2006), electric-powered vehicles could replace about 99 % of oil used in conventional cars, assuming similar well-to-tank energy efficiencies. GHG emission savings can also occur, but are not guaranteed. Already, a number of alternatives to petrol are in use, but only ethanol from sugar cane is not fossil-fuel based. The BTRE (2005) estimates for Australian passenger car fuel consumption in energy terms for 2004 and base case projections for 2020 are shown in Table 1. Clearly, little change is expected to occur in this base case projection.

Fuel	2004 (%)	Projected 2020 (%)
Petrol	89.9	85.9
LPG	5.7	5.3
Diesel	4.3	7.8
NG	0.2	0.7
Ethanol	0.1	0.3
All fuels	100.0	100.0

Table1 Passenger car fuel consumption, 2004 and 2020 base case (source BTRE 2005).

Could LPG, compressed natural gas (CNG) and ethanol become major alternatives to petrol and diesel by 2030? The GHG emission reduction benefits of LPG over petrol can only be minor, but what about CNG? An MIT study (Weiss et al 2000) found that a mid-sized hybrid sedan could have a well-to-tank energy efficiency of 1.09 v-km/MJ for diesel, and 0.97 for CNG. In terms of CO_2 emissions the results favoured CNG with 17.6 v-km/kg CO_2 compared with 14.2 for diesel. However, the same study found that this advantage will be offset by any methane leakage emissions from NG distribution, compression, refuelling and on-board storage. In brief, Australia's relatively abundant NG reserves could help solve oil depletion, but will be of little help in reducing transport GHG emissions compared with conventional petroleum fuels. Synthetic liquid fuels could be made from our even more more abundant coal reserves, but would double the GHG penalty compared with petrol (Socolow 2005). Accordingly, the rest of this section first looks at the remaining alternative fuel in Table 1, ethanol (or more generally any biomass-based liquid fuel), for existing vehicle types, then at various renewable energy options for alternative propulsion system vehicles.

Australian ethanol is presently derived from wheat and cane sugar, of which Australia is a leading exporter. Ethanol from lignocellulose would improve energy returns and GHG savings, but is nowhere in commercial production. Although the potential is much higher than for ethanol from starchy food crops, dedicated biomass energy plantations would also compete with food crops (and forests and pastures) for fertile, well-watered, land. Mardon (2007) points out that half of Victoria would need to be under energy plantations to provide for its present liquid fuel needs. Australia exports much of its agricultural production to pay for imports; such exports could be even more vital in future if our coal exports collapse in a greenhouse-concious world. Agricultural and forest residues have low input energy and money costs, but most should be retained for soil fertility and erosion control. Furthermore, the net energy return for cellulosic ethanol could also prove to be marginal (Moriarty and Honnery 2007b).

Further, oil depletion and global climate change are not the only environmental challenges we face. An incomplete list would include loss of biodiversity, declining per capita availability of fresh water, soil erosion and declining soil fertility, and air, water and ground pollution. These additional challenges to environmental sustainability further complicate the task of reducing emissions from private transport, since it is necessary that proposed solutions such as biofuels do not worsen these other environmental/resource problems.

Overseas, enthusiasm for pure battery electric vehicles faded when the difficulty of matching the range of internal combustion vehicles became apparent. The new focus is on plug-in hybrids, building on the sales success of hybrid cars (Romm 2006). Plug-in hybrids would normally run off an electric motor powered from rechargeable batteries, but could also run on petrol or other liquid fuels from their small conventional engines, thus extending their range.

The major global car companies in recent years have also shown much interest in hydrogen fuel cell vehicles. But a number of studies have shown that when mains electricity is the primary energy source for both plug-in hybrid vehicles and hydrogen fuel cell vehicles, plug-in hybrids are far more energy-efficient. Specifically, when a given car model is a plug-in battery hybrid vehicle, running off its battery, its well-to-wheels energy efficiency will be about four times higher than when powered by a hydrogen fuel cell, with the hydrogen produced by electrolysis of water (Ramesohl and Merten 2006, Romm 2006). GHG emissions will follow a similar pattern.

But in grids that are less than 100 % renewable, overall GHG emissions will always be less if available renewable electricity is used directly (lighting or refrigeration, for example), rather than to charge batteries or produce electrolytic hydrogen for transport (Ramesohl and Merten 2006). The reason is that much energy is lost during battery charge/discharge, or from electricity conversion to hydrogen. Further, fossil fuels, largely coal, accounted for 92 % of Australian electricity production in 2003, compared with only about 63 % for high-income countries overall

(World Bank 2006). Battery vehicles in Australia will thus deliver fewer v-km/ kg $CO_{2\text{-}e}$ compared with petrol or diesel hybrids.

Not only will the shift to renewable energy for Australian electricity generation be a slow process, but at present the reverse is happening. In 2003, only 8.0 % of our electricity came from renewable resources, down from 9.6 % in 1990 (World Bank 2006). ABARE (Dickson et al 2002) project that renewable energy will only generate 9.4 % of electricity in 2020. The long lives of fossil fuel power plants (as long as 60 years for coal-fired plants (Socolow 2005)), in a sense 'lock' us into a continuing high-carbon future. Globally, the position is similar. The International Energy Agency (IEA) (2006) assume that for the world overall, fossil fuels will slightly increase their share of total primary energy from 80.6 % in 2004 to 81.2 % in 2030.

Thus, even if the present rapid growth in wind and solar electricity continues in Australia, renewables will at best increase their share of electricity only marginally by 2030 or even by 2050, given their present small share. If large cuts in GHGs prove necessary, it is unlikely that the current growth in our electricity output, currently about 4 % per annum (ABS 2007), will continue. Output would stagnate or even decline, inhibiting replacement of existing power plants by renewable electricity. It follows that replacing all or part of car fuels by electricity—or hydrogen derived from electricity—will not reduce GHG emissions from the Australian car fleet for several decades to come.

Alternative fuels are not the only means proposed for overcoming the climate change effects of fossil fuel use. Geo-engineering and carbon capture and sequestration are technologies that could potentially allow their continued use. But geo-engineering proposals to offset rising global temperatures would exacerbate the 'other CO_2 problem', ocean acidification, since CO_2 emission would continue, with much of it absorbed in the oceans (Moriarty and Honnery 2006). Additionally, it would be very difficult to obtain international agreement on suitable measures, which in any case would be subject to great uncertainties, and may need to be continued—at great annual cost—for 1000 years (MacCracken 2006).

An IPCC report (IPCC 2005), optimistic on the potential for carbon capture and storage, concluded that by 2050, only 20-40 % of global fossil fuel CO_2 could be 'technically suitable for capture'. Given the many economic and political problems still to be resolved surrounding carbon storage (Huesemann 2006, Moriarty and Honnery 2006, Schrag 2007) it seems unlikely that carbon sequestration will be significant by 2030. And, of course, neither geo-engineering or carbon sequestration will ameliorate transport's oil depletion problem.

Overall, the above analysis suggests that by 2030, the tank-to-wheel efficiency of the Australian car fleet might be raised by a factor of 2-2.5 with concerted effort, but that well-to-tank fuel efficiency will continue to fall, partly offsetting these gains. Increases in vehicle occupancy and a shift to non-carbon fuels could potentially also raise p-km/$CO_{2\text{-}e}$, but both factors are presently working to lower it. At best, with strong policy support, technical fixes might reduce fleet $CO_{2\text{-}e}$ emissions per pass-km about two-fold by the year 2030, a long way short of that needed to meet our GHG emission reduction targets, or probably even our oil depletion problems.

5 Sustainable Australian passenger transport

The preceding sections examined various options for decreasing both oil use and GHG emissions per p-km of car travel, and concluded that large reductions in either could not be expected any time soon. This section briefly evaluates the changes needed in Australian surface transport.

If, as we have argued, a sustainable Australian passenger travel system cannot be based around cars, can alternative transport systems provide sustainable mobility? For public transport to be considered as a replacement, its p-km/kg $CO_{2\text{-}e}$ must not only be higher than for cars today, but must also have better future prospects. In 2004, electric passenger rail (both heavy and light rail) delivered 8.55 p-km /kg $CO_{2\text{-}e}$, and diesel heavy passenger rail 13.25 p-km /kg $CO_{2\text{-}e}$. In contrast, assuming 1.4 occupants per car, passenger cars in 2004 delivered 5.52 p-km /kg $CO_{2\text{-}e}$ (BTRE 2005). Diesel buses should be similar to diesel rail in GHG efficiency. Overall, public transport today is probably about twice as GHG-efficient as present car travel. Unfortunately, because coal is our dominant power station fuel, electric public transport is superior from an oil-reduction and supply security viewpoint, but presently not as good as diesel public transport for GHG reduction.

Public transport occupancy rates could be much improved if vehicular travel shifts from car to public transport. Patronage increases can often initially be accomodated on existing services, with additional services added as extra capacity is required. The result will be higher overall seat occupancy. (In contrast, attempts to boost public transport patronage in normal circumstances by providing more services often leads to lower occupancy rates.). Historical occupancies provide indirect evidence for this trend. Between 1960 and 1980, large losses in urban public transport patronage were accompanied by declines in passenger loadings. Melbourne trams, for example had average loading of 24.6 in 1960, but only 18.3 by 1980 (Newman and and Kenworthy 1989). In Australia, a doubling of national public transport occupancy rates might be possible, even though overcrowding is already a problem on some services. With existing technology, such higher possible loadings might give public transport a 4-fold (i.e. 2 x 2) advantage over existing car travel in p-km/kg $CO_{2\text{-}e}$.

Bus fuel economy gains could be expected to follow the same path as for cars. However, buses (and non-electric trains) are already diesel-fuelled, with relatively efficient engines. Given the high vehicle mass per seat ratio for rail transport, there is still scope for further efficiency gains, and part of this might be realised by 2030. Renewable energy for electric public transport vehicles, as for electric cars, will take several decades to implement. Akerman and Hojer (2006) assume a doubling of fleet efficiency, at constant passenger loading, is possible for both buses and trains by 2050 in Sweden. Here we assume that p-km/MJ can be raised by a factor of 1.5 by 2030 for all public transport modes at constant loadings. For no change in fuel mix, p-km/kg $CO_{2\text{-}e}$ would rise a similar amount. Thus a public transport system in 2030 might at best be six (i.e. 4 x 1.5) times as $CO_{2\text{-}e}$ efficient as a fully car-based one with present vehicle fuel efficiencies and occupancies. If todays passenger travel levels were to be maintaned in a fully public transport system, a more than three-fold reduction in net transport $CO_{2\text{-}e}$ by 2030 would still be required to meet the 18.8-fold reduction suggested above. To allow for future population growth, even greater reductions would be needed.

It follows that Australian motorised surface travel itself will need to be lowered. However, a surface transport system based on public transport will have much lower overall passenger travel than one based on private cars, for several reasons:

- The structure of Australian private motoring costs favours higher levels of travel, since fixed costs, especially depreciation, registration and insurance, predominate. Motorists' travel costs per v-km are thus minimised at higher annual levels of vehicle use.
- Serving the travel needs of others involves higher levels of passenger travel compared with alternative modes. For example, a parent chauffering a child to school involves two

person trips from home to school and one person trip from school to home. In contrast, travelling by bus involves only one vehicular trip (and walking to school none at all).

- Car travel, particularly driving, provides psychological benefits to motorists. To a much greater extent than alternative travel modes, car travel is not solely a derived demand, undertaken to gain access to out-of-home activities (Moriarty and Honnery 2005). 'Going for a drive' can be the reason for a trip. Additionally, car travel provides protection from the elements, freedom from timetables, privacy, and the ability to carry heavy luggage or shopping purchases, all of which encourage more trip-making than would an alternative transport system.

Some researchers also argue that for cities at least, land use changes, particularly increases in urban population densities, or application of the new Information Technology (IT), can greatly reduce the need for travel. Australian large cities show little or no travel variation with density (Moriarty and Honnery 2005). Perhaps more importantly, major land use changes are not possible within the restricted time frames for averting global climate change or oil depletion. Land use changes in our cities will likely follow travel reductions, not lead them. IT and transport are sometimes substitutes in particular situations, but overall up till now they seem to have complemented each other, as both have historically grown in step. Nevertheless in a transport-constrained future, IT could be of considerable use in coping with lower levels of travel.

Our travel patterns (and the activity patterns which underlie them) will have to change to accommodate lower vehicular travel levels. Some of the reductions can be compensated by much higher levels of non-motorised travel—walking and cycling. At present, non-motorised travel typically only amounts to about one km daily per capita (Moriarty 2002), but its value for exercise and weight reduction could cause its level to rise in future. And although large-scale changes in urban form cannot happen fast, changes at the micro-level can. More use can be made of local shopping, entertainment, and recreation centres, and of those destinations easily accessible by public transport. Travellers will once more get used to combining previously separate vehicular trips. Particularly in the transition to the new system, these changes will be easier for inner city residents, and harder for outer suburban or non-urban residents with less provision for alternative modes.

Travel modes can be compared along many dimensions, including equity, land use efficiency, energy efficiency, air pollution, traffic casualty rates, travel times, comfort and privacy. Cars are superior to alternatives on some dimensions, inferior on others. In Australia, we have chosen to focus on those qualities of travel where cars perform well, and downplay the others as far as possible. Changes will thus have to occur in the way we think about travel. For example, although in general we seemingly place high value on efficiency (even, increasingly, on vehicular fuel efficiency), such is not the case for 'travel efficiency'—getting the maximum benefit from a given amount of travel.

So far, we have given a brief outline of the changes needed to our travel system. Profound policy changes will be required to bring about the desired reductions. Of course, transport oil consumption and emissions can be reduced to any level desired by application of sufficiently high road use taxes or fuel prices. Given continued depletion of Australian and global oil reserves, further externally-imposed price rises for petrol are probable, leading to further reductions in Australian petrol use and associated emissions. But economic approaches alone for very large cuts in emissions are inequitable, given the greater travel needs, lower access to public transport, and lower average incomes of outer suburban and non-metropolitan residents. A more equitable approach would be to lower maximum road speeds to as low as 30 km/h, as discussed above. Further policy measures could include traffic-free precincts, greater parking restrictions, an end to further arterial road building, and incentives for alternative travel modes.

It can be argued that the reductions discussed here—an almost 19-fold reduction in travel emissions, and even more per p-km if allowance is made for population (and thus travel) growth—is too high, and politically impossible to achieve. But even if Australia aimed for only a quarter of this, say a 5-fold reduction by 2030, our analysis suggests that it could not be met through technical measures such as alternate fuels or improved efficiency. Of course we—and the world overall—can set easier targets, but they will not help avert climate change. And the dismal history of the Kyoto treaty shows that apparently 'politically feasible' targets can be difficult to meet, if attempts are made to meet them in a 'business-as-usual' framework.

6 Conclusions

Car travel in Australia faces two major challenges: global climate change from greenhouse gas emissions and depletion of both Australian and global oil reserves. Given the success of technical measures in controlling vehicular air pollution, many researchers advocate technical solutions to overcome the above two challenges as well. The present study argues that it is not possible to find technical solutions for these problems, for the following reasons:

- At best a 2- to 2.5-fold fuel efficiency gain can be hoped for out to 2030, with most of the potential gain resulting from a switch to hybrid electric vehicles. Even these improvements could be offset by both continued decline in car occupancy rates and increasing energy costs for petroleum-based fuels.
- Success in drastically reducing GHG emissions and oil use therefore depend crucially on electricity derived from renewable energy, or renewable biomass-based liquid fuels, replacing most petroleum-based fuels. However, available renewable energy resources usually either have limited further potential or are not carbon-neutral. All will take more than a few decades to form a major share of electricity generation. Indeed, at present, non-carbon energy sources are declining as a share of Australian electricity inputs

In the absence of technical solutions to the twin challenges facing car travel, Australia will instead have to move to a surface transport system based largely on use of alternative modes. Because even a full shift to public transport will not bring about all the reductions needed, vehicular travel levels will need to be reduced threefold or even more, depending on population growth. Such travel reductions will require far more use of local destinations, accessed on foot or by bicycle, with more energy-efficient public transport modes providing the much-reduced vehicular share of travel. In addition, virtual travel will have to replace some physical travel. Similar changes will be needed in other areas of our transport, particularly air travel, and may prove as difficult to achieve—if we attempt to rely solely on technology for solutions.

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References

Akerman, J and Hojer, M (2006) How much transport can the climate stand?—Sweden on a sustainable path in 2050 *Energy Policy 34*,1944-1957

Association for the Study of Peak Oil and Gas (ASPO) (2007) *ASPO Newsletter No 80* August (Also earlier newsletters) Accessed at www.peakoil.net

Australian Bureau of Statistics (ABS) (2006a) *Motor Vehicle Census Australia* ABS Cat No 9309.0 Canberra: Government Printer

ABS (2006b) *Survey of Motor Vehicle Use Australia 31st October 2005* (and previous surveys) ABS Cat No 9208.0 Canberra: AGPS

ABS (2007) *Commonwealth Yearbook* (Also earlier editions) Canberra: AGPS

Bows, A and Anderson, K L (2006) Policy clash: can projected aviation growth be reconciled with the UK Government's 60 % carbon-reduction target? *Transport Policy* doi :10.1016/j.tranpol.2006.10.002

BP (2007) *BP Statistical Review of World Energy 2006* (56th edition) (Also earlier editions) London: BP

Broecker, W S (2007) CO_2 Arithmetic *Science 315*, 1371

Bureau of Transport and Resource Economics (BTRE) 2005 *Greenhouse Gas Emissions from Australian Transport: Base Case Projections to 2020* Canberra: Department of Environment and Heritage

Campbell, C J (2006) The Rimini Protocol an oil depletion protocol: heading off economic chaos and political conflict during the second half of the age of oil *Energy Policy 34* (12), 1319-1325

Cleveland, C J (2005) Net energy from the extraction of oil and gas in the United States. *Energy 30*, 769-782

den Elzen, M and Meinshausen, M (2006) Multi-gas emission pathways for meeting the EU 2 ºC climate target, pp 299-309 of Shellnhuber, H J Cramer, W Nakicenovic, N Wigley, T and Yohe, G (eds), *Avoiding Dangerous Climatic Change* Cambridge: CUP

den Elzen, M Meinshausen, M and van Vuuren, D (2006) Multi-gas emission envelopes to meet greenhouse gas concentration targets: costs versus certainty of limiting temperature increase *Global Environmental Change* doi :10.1016/j.gloenvcha.2006.10.003

Dickson, A Short, C Donaldson, K and Roberts, A (2002) Australian energy: key issues and outlook to 2019-20 *Australian Commodities 9* (1), 198-208

Dynamic Transport Management (1997) *Fuel Consumption Project: Final Report* Canberra: Dept. of Primary Industries and Energy

Energy Information Administration (EIA) (2007) *International Energy Outlook 2007* US Dept. of Energy (DoE)

Hansen, J Sato, M Ruedy, R et al (2006) Global temperature change *PNAS 103* (39),14288-14293

Huesemann M H (2006) Can advances in science and technology prevent global warming? *Mitigation and Adaptation Strategies for Global Change 11*, 539-577

Intergovernmental Panel on Climate Change (IPCC) (2005) *Carbon Dioxide Capture and Storage* IPCC Special Report. Cambridge, U.K: CUP

International Energy Agency (IEA) (2006) *Key World Energy Statistics 2006* Paris: IEA/OECD

Leggett, J (2006) *The Empty Tank* New York: Random House

Lovins, A B (2005) More profit with less carbon *Scientific American* September, 52-61

MacCracken, M C (2006) Geoengineering: worthy of cautious evaluation? *Climatic Change 77*, 235-243

Mardon, C (2007) The feasibility of producing alcohol fuels from biomass in Australia *International Journal of Global Energy Issues 27* (2), 138-159

Moriarty, P (1997) The future for Australian personal passenger travel *Road & Transport Research 6* (3), 4-12

Moriarty, P (2002) Household travel time and money expenditures *Road & Transport Research 11* (4), 14-23

Moriarty, P and Honnery, D (1999) Slower, smaller and lighter urban cars *Proceedings of the Institution of Mechanical Engineers Part D 213*, 19-26.

Moriarty, P and Honnery, D (2005) Determinants of urban travel in Australia, CD-ROM paper CS4B of *Papers of the Proceedings of the 28th Australasian Transport Research Forum 28*, Sydney: ATRF

Moriarty P, and Honnery, D (2006) Intermittent renewable energy: the only future source of hydrogen? *International Journal of Hydrogen Energy* doi:10.1016/j.jhydene.2006.12.008

Moriarty P, and Honnery, D (2007a) The prospects for global green mobility. Submitted for publication

Moriarty P, and Honnery, D (2007b) Global bioenergy: problems and prospects *International Journal of Global Energy Issues 27* (2), 231-249

Moriarty, P and Mees, P (2006) The journey to work in Melbourne, CD-ROM of *Papers of the Proceedings of the 29th Australasian Transport Research Forum 29*, Gold Coast: ATRF

Newman, P and Kenworthy, J (1989) *Cities and Automobile Dependence: An International Sourcebook* London: Gower

Noland, R B Cowart, W A and Fulton, L M (2006) Travel demand policies for saving oil during a supply emergency *Energy Policy 34*, 2994-3005

Ory, D T and Mokhtarian, P L (2005) When is getting there half the fun? Modeling the liking for travel *Transportation Research A 39*, 97-123

Overpeck, J T and Cole, J E (2006) Abrupt change in earth's climate system *Annual Reviews of Environment and Resources 31*, 1-31. doi:10.1146/annurev.eg.31.092506.100011

Overpeck, J T, Otto-Bliesner, B L Miller, G H et al (2006) Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise *Science 311*, 1747-1750

Petrie, E et al, Geosciences Australia (2005) *Oil and Gas Resources of Australia 2003* Canberra: Geosciences Australia

Ramesohl, S and Merten, F (2006) Energy system aspects of hydrogen as an alternative fuel in transport *Energy Policy 34*, 1251-1259
`

Romm, J (2006) The car and fuel of the future *Energy Policy 34*, 2609-2614

Romm, J J and Frank A A (2006) Hybrid vehicles gain traction *Scientific American* April, 56-63

Schrag, D (2007) Preparing to capture carbon *Science 315*, 812-813

Socolow, R H (2005) Can we bury global warming? *Scientific American* July, 39-45

Soderbergh, B Robelius, F and Aleklett, K (2006) A crash programme for Canadian oil sands industry *Energy Policy* doi:10.1016/j.enpol.2006.06.007

Solomon, S Qin, D Manning, M Chen, et al (2007) (eds) *Climate Change 2007: The Physical Science Basis* Cambridge, UK: CUP

Turton, H (2006) Sustainable global automobile transport in the 21st century: an integrated scenario analysis *Technological Forecasting & Social Change 73*, 607-629

Urry, J (2006) Inhabiting the car, pp.17-31 of Bohm, S Jones, C Land, C and Paterson, M. (eds) *Against Automobility* Oxford: Blackwell Publishing/Sociological Review

Weiss, M A Heywood, J B Drake, E M et al (2000) *On the Road in 2020: A Lifecycle Analysis of New Automobile Technologies* Energy Laboratory Report # MIT EL 00-003

World Bank (2006) *2006 World Development Indicators* (Also earlier editions) New York: World Bank

Zimov, S A, Schuur, E A G and Chapin, F S (2006) Permafrost and the global carbon budget *Science 312*, 1612-1613