THE EFFECT OF NEW TECHNOLOGIES IN ROAD VEHICLE PROPULSION ON COST-BENEFIT ANALYSES OUTCOMES

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ABSTRACT

This paper examines the effect that new vehicle technologies would have on fuel consumption related project benefits in a cost-benefit analysis. Fuel consumption affects fuel cost savings, reduction in greenhouse gas emissions and a decrease in tailpipe air pollution. The paper found that the effect of technological change on economic cost-benefit analysis results depends largely on the unit value applied to greenhouse gas emissions. Standard unit prices of carbon emissions, which are currently stipulated in commonly applied guidelines documents, are substantially lower than that quoted in some recent reports. Switching to alternative energy vehicles would have relatively little effect on cost-benefit analysis results if results were based on lower unit price estimates, but using the higher carbon cost estimates of the Stern Review show that new technology would have a substantial effect on project benefits. Due to consumers' propensity to upgrade to larger vehicles as engines becomes more efficient, improving specific fuel consumption without switching to alternative energy types would, however, have relatively little effect on average fuel consumption across the vehicle fleet.

1. INTRODUCTION

1.1 Background

Vehicle characteristics have a significant impact on a transport project's economic performance. While cost-benefit analysis traditionally focussed on forecasting project benefits, changes in vehicle characteristics during the evaluation period are usually ignored. Given the anticipated radical changes in new vehicle propulsion technologies, rapidly changing pollution standards and government policy interventions (such as compulsory vehicle scrapping), such an approach may no longer be realistic.

This paper examines the most likely vehicle technologies to emerge in future and how these technologies might change vehicle operating cost and emissions. We also propose approaches to measuring vehicle operating cost of alternative fuel vehicles, particularly battery and fuel cell vehicles whose emissions are produced upstream, and the environmental life cycle cost of vehicle ownership. We would then test the effect of the most likely scenarios on economic evaluation outcomes through a case study.

[1] The views expressed in this paper are those of the author and are not necessarily endorsed by Parsons Brinckerhoff. Neither the author, nor Parsons Brinckerhoff, would accept liability for consequences which may result from the use of the results and data.

2. THE EFFECT OF FUEL CONSUMPTION

2.1 What types of technological change to expect

Technological innovation, particularly radical breakthroughs in completely new methods of energy extraction and propulsion, is extremely difficult to predict. Our paper therefore focuses on known technologies, which could have a large impact on fuel consumption if their practical and cost constraints could be overcome.

Although numerous vehicle variations exist, new technologies fall roughly in two categories. The first group convert energy to traction from conventional fuels (petrol, diesel, LPG) with an internal combustion engine. Technological advances in this group would stem mainly from improving the efficiency of the internal combustion engine (see Table 1). This includes petrol-electric hybrid powertrains, which uses an internal combustion engine to generate the electricity to power its electric motor. The manufacture and on-board storage of these fuels poses relatively few challenges.

The second group primarily uses electric motors powered by electricity generated from alternative fuels, such as hydrogen in the case of fuel cell vehicles, or any number of sources in the case of plug-in battery electric vehicles. Although the technology exists to produce highly efficient electric motors cheaply, the main challenges are to produce the fuel (in the case of hydrogen fuel cell vehicles), the cost effective on-board storing of fuel in sufficient quantities (hydrogen fuel cell and batteries), and refuelling vehicles quickly and safely (see Table 1).

Table 1 Focus, feasibility, benefits and constraints of each fuel source

Fuel source	Focus and feasibility	Benefits	Constraints
Petrol	▪ Focus on improved efficiency ▪ Smaller turbocharged engines ▪ Two/four stroke ▪ Availability of fuel ▪ Refinement of known technology	▪ Cheap ▪ Known basic technology	▪ Peak oil may threaten availability of fuel ▪ Still producing tailpipe GHG
Diesel	▪ Availability of fuel ▪ Refining existing technology ▪ Focus on improved efficiency ▪ Common rail ▪ New exhaust catalysts plus fuel additives	▪ Diesel contains more energy than petrol ▪ More efficient – more energy converted to power, less waste heat ▪ Lower fuel consumption, hence lower CO_2 emissions	▪ NOx emissions remain – one of the worst tailpipe GHG ▪ High combustion temperatures increase NOx emissions ▪ Precision fuel systems which is difficult to calibrate
Biodiesel	▪ Engines not calibrated for use ▪ Finding sufficient raw materials ▪ Improved fuel standards ▪ Diverse raw materials ▪ Synthetic fuels available in around 10 years time	▪ Theoretically it is renewable, which would reduce CO_2 ▪ Easy to blend with pump fuel, so it can already be introduced	▪ Large scale production could have other negative environmental consequences ▪ Could damage fuel supply and engine lubrication system ▪ Could change chemical formulation with time and with heat ▪ May emit harmful gases linked to cancer

Fuel source	Focus and feasibility	Benefits	Constraints
Bio-ethanol	▪ Tested, Brazil has used it for many years. ▪ Only minor engine modifications required ▪ Uses fermentation of either pure sugar, starch or cellulose	▪ Unlike biodiesel, all types of ethanol have the same chemical properties, irrespective of source.	▪ If made through fermentation (e.g. sugar extraction), process releases CO_2. New technology could reduce this by 90% ▪ Corrosive effects on fuel supply system ▪ Contains 30% less energy than petrol – higher fuel consumption ▪ Could cause cold start problems in concentrated form ▪ Difficult to optimise engines for both petrol and ethanol (flex fuel cars)
Hybrid	▪ They have been around for 10 years, therefore a known technology ▪ More and more manufacturers are embracing the technology. ▪ Most cars in future likely to be form of hybrid (mild or micro hybrids) ▪ Plug-in hybrids	▪ Good for making an environmental statement and creating global awareness ▪ Most efficient around town ▪ Some of the technologies could be used in fuel cell cars and electric plug-inns	▪ Technically and mechanically complex. ▪ Environmental impact of battery packs, especially if they are not properly recycled. ▪ Fossil fuel still involved to produce propulsion ▪ Complex to make and expensive ▪ Adds a lot of weight to the car, offsetting some of the efficiency benefits of powertrain
Hydrogen fuel cell	▪ There are many working prototypes ▪ Commercially available	▪ Runs on hydrogen which produces zero tailpipe emissions ▪ Some consider hydrogen gas as being safer than petrol ▪ Hydrogen could be renewable, and the energy used to produce it could come from renewable resources ▪ Drivetrain potentially more reliable than petrol or diesel engines (less moving parts)	▪ The main challenge is to produce vehicles economically ▪ Not currently a widespread fuel supply network. ▪ Large investment required to develop the fuel supply infrastructure ▪ Hydrogen is difficult to transport and store ▪ Expensive to produce ▪ Production requires energy that could involve fossil fuels, thereby merely shifting GHG emissions.
Plug-in battery electric	▪ Nickel metal Hydride and Lithium Ion are two favourite battery technologies ▪ Has long history of urban application and becoming more widespread. ▪ Significant technical constraints to overcome before it becomes mainstream	▪ No tailpipe emissions ▪ No fuel transport and storage cost ▪ Powertrain potentially more reliable than petrol or diesel engines (less moving parts)	▪ Vehicle range ▪ Electricity for recharge are mainly generated using fossil fuel ▪ Batteries are expensive ▪ Environmental impact of battery packs, especially if they are not properly recycled. ▪ Batteries have a limited life, and if not treated well, they lose capacity quickly. ▪ Long charging time for batteries ▪ Lack of charge points

Although some of these new technologies have significant practical problems to overcome, such as establishing new fuel manufacturing and supply networks in the case of fuel cell, or technical constraints to resolve, such as the on-board fuel storage problems associated with fuel cell and battery electric vehicles, it is mostly the cost of introducing new technologies that will determine their widespread acceptance in the market. It would therefore be fair to assume that new technologies would only become mainstream when their capital and maintenance cost are on par with that of conventionally powered vehicles. Our comparative analyses therefore focus only on the fuel consumption and emissions variables, and assume that new technologies could be bought at a competitive price.

2.2 Contribution of fuel consumption related benefits to total project benefits

Average vehicle fuel consumption directly affects three benefit components of the cost-benefit analysis; fuel cost savings, reduction in greenhouse gas (GHG) emissions and a decrease in vehicle tailpipe air pollution. Standard cost-benefit analysis (CBA) reporting practice usually group fuel consumption with other vehicle operating cost components, such as capital and maintenance, whereas GHG and air pollution falls under environmental benefits, which also include noise pollution, nature and separation impacts. Consequently, the full impact of fuel consumption on project benefits is often overlooked.

Using Austroads (2008) and ATC (2006) unit cost data, the significance of fuel consumption related benefits is demonstrated by the following case study of a commuter rail line expansion on the fringes of one of Australia's capital cities (see Figure 1). These results, which are typical of many other transport projects, show that fuel consumption related benefits form only about a quarter to total benefits. Significant shifts in these benefits over the evaluation period resulting from technological change may therefore significantly affect a project's overall economic performance.

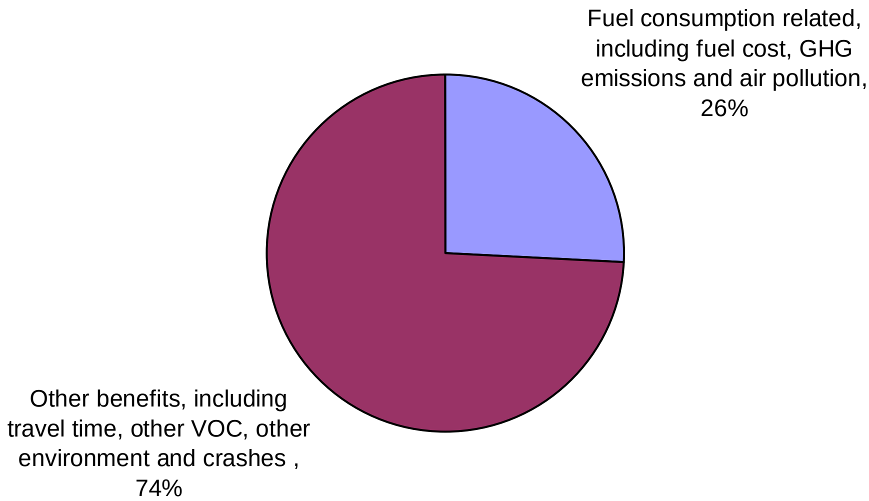

Figure 1 Fuel consumption related benefits as percentage of overall benefits.

Considering the contribution of fuel consumption related benefit components, Figure 2 shows that 49% of fuel consumption related benefits result from air pollution and GHG due to reduced tailpipe emissions. The main implications of this are, firstly, that new technologies could, in addition to reducing the overall level of emissions, move air pollution upstream to areas where they would have less impact (this would not apply to GHG, which is equally damaging no matter where it is produced).

Secondly, the amount of fuel consumption related benefits are calculated from unit values that are based on shadow prices, which relies heavily on highly controversial (and emotional) assumptions. We would therefore also have to consider the assumptions under which unit values are determined to assess the full impact of technological change. This issue is discussed in Section 3.

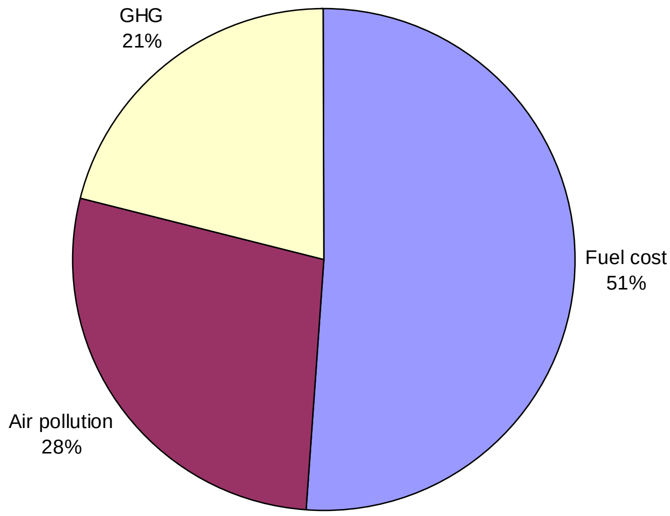

Figure 2 Breakdown of fuel consumption related benefits

2.3 Effect of technology on specific fuel consumption and emissions

When considering the effect of technology on fuel consumption and emissions, it is important to differentiate between specific and average fuel consumption. Specific fuel consumption refers to a particular vehicle type, whereas average fuel consumption is what the entire vehicle fleet achieves in practice. This section focuses on the specific fuel consumption, whereas Section 2.4 considers the average fuel consumption of Australia's vehicle fleet.

The main challenges with vehicle-type comparisons are that, firstly, some of the new vehicle classes generate power from unconventional (for road vehicles) fuel sources, making it impossible to base the comparison on fuel consumption. Secondly, new engine types have widely different efficiencies in converting fuel to energy (production efficiency), and in converting energy to motive power (vehicle efficiency). Thirdly, national guidelines, such as ATC, Austroads and Transport NZ do not provide methods for calculating energy efficiency, or standard units in which it should be expressed.

In the absence of guidelines and standards, we have based our calculations on the methods proposed by Eberhard & Tarpenning (2006) and Chaster & Horvath (2009). In order to make a fair comparison between different vehicle types, we have assumed that all forms of energy are extracted from fossil fuels, either natural gas or crude oil. Obviously, hydrogen and electricity could be produced from other types of fuel, including sustainable sources. Not only would this have a profound impact on the amount of GHG and air pollutants, but also on the cost of energy. This type of modelling, which is considerably more complex, is outside the scope of this paper.

Table 2 lists the energy consumption of a typical vehicle in each technology category from worst to best. Although not all the vehicles are currently offered in Australia, they are currently commercially available in other major markets. It should also be noted that the selection of the Tesla Roadster as an example of a battery-electric car was motivated by the fact that its output is more comparable to current large family cars, rather than small micro cars which are currently the most common type of plug-in electric vehicle.

Table 2 Comparison of fuel consumption of different engine and fuel technologies

Technology	Example car	Primary fuel source	Energy production efficiency	Energy consumption		Vehicle efficiency (km/MJ)	Overall energy efficiency (km/MJ)
Petrol engine	Toyota Camry	Crude oil	81.7%	8.6	l/100km	0.37	0.28
Natural gas engine	Honda CNG	Natural gas	86.0%	6.7	l/100km	0.57	0.32
Hydrogen fuel cell	Honda FCX	Natural gas	61.0%	103.0	km/kg	0.53	0.35
Diesel engine	VW Jetta	Crude oil	90.1%	4.7	l/100km	0.63	0.48
Petrol/electric hybrid	Toyota Prius	Crude oil	81.7%	4.3	l/100km	0.78	0.56
Plug-in battery electric	Tesla Roadster	Natural gas	52.5%	110.0	Wh/km	2.18	1.14

Table 3 shows the conversion of energy consumption data from Table 2, to GHG emissions.

Table 3 Comparison of GHG emissions of different engine and fuel technologies

Technology	Example car	Source fuel	CO_2 content (g/MJ)	Energy cons. (km/MJ)	CO_2 emissions (g/km)
Petrol engine	Toyota Camry	Crude oil	19.9	0.28	72.4
Natural gas engine	Honda CNG	Natural gas	14.4	0.32	45.0
Diesel engine	VW Jetta	Crude oil	19.9	0.48	41.5
Hydrogen fuel cell	Honda FCX	Natural gas	14.4	0.35	41.1
Petrol/electric hybrid	Toyota Prius	Crude oil	19.9	0.56	35.5
Plug-in battery electric	Tesla Roadster	Natural gas	14.4	1.14	12.6

The results in Tables 2 and 3 show that:

- There is extensive scope for improving energy consumption and GHG emissions, even with existing commercially available technology. A commercially available high performance plug-in electric car is four times more energy efficient, and produces six times less CO_2 than the typical petrol powered Australian family sedan. The main constraint to achieving these benefits now is the high capital cost of vehicles related to storing energy, in the case of hydrogen fuel cell and plug-in battery electric cars, and energy recharge time, in the case of a plug-in battery electric car.

- As expected, energy consumption has a direct impact on emissions. However, it is interesting to note that the impact is not linear, e.g. although the energy consumption of the natural gas powered car is 14% lower than the petrol car, it produces 38% less CO_2 per kilometre.

- Even if hydrogen and electricity is produced from fossil fuels, the adverse effects of air pollution could theoretically be eliminated by moving generation to areas where it would have a limited impact on the environment. (The amount of GHG would obviously remain constant, regardless of where it is produced.) As air pollution makes a substantial contribution to energy consumption related benefits (see Figure 2), this could have a significant influence on the benefits of alternative vehicle technologies, even if fossil fuels are used in the production of vehicle propulsion energy.

- The potential exists to eliminate GHG emissions and air pollution completely by producing fuel through sustainable means.

Using the data in Tables 2 and 3, we calculated the effect on project benefits of switching to alternative vehicle technologies. The results of our case study in Figure 3 show that, if all other parameters are fixed, a 24% decrease in project benefits could at best be expected with the introduction of an all electric vehicle fleet. Taking account of the fact that adoption of alternative vehicle technologies would be a relatively slow process, and that the analysis at this point excluded behavioural change (see Section 2.4 below), the impact of alternative vehicle technologies would in practice be relatively minor.

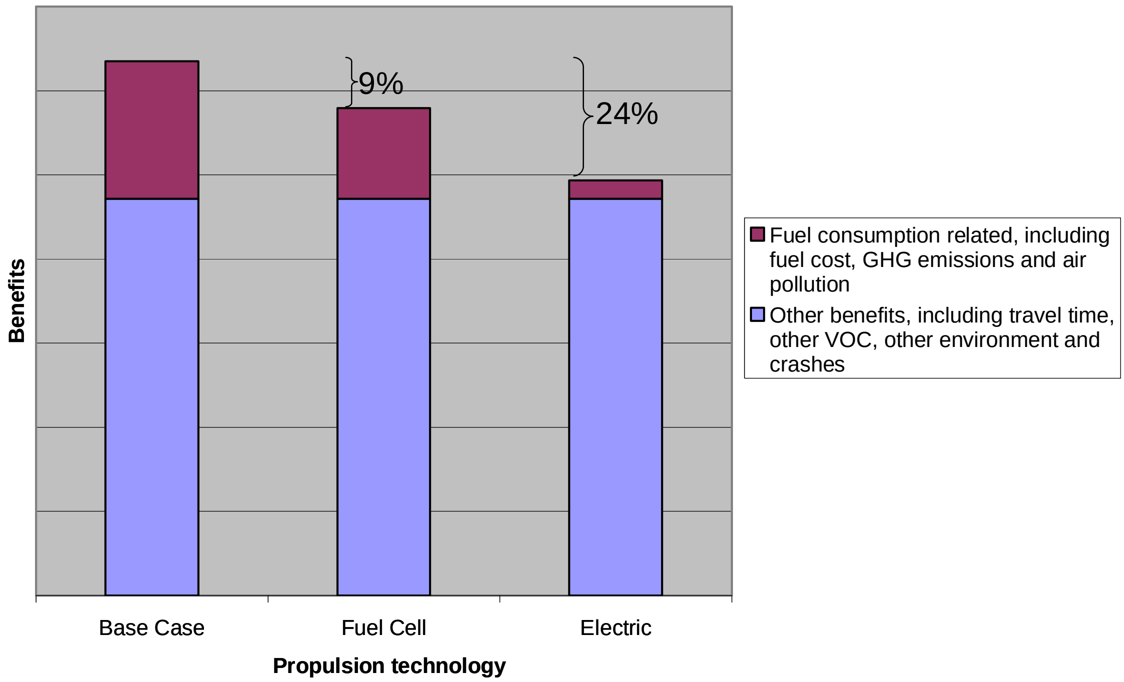

Figure 3 Impact on project benefits of switching to alternative vehicle technology

2.4 Effect of technology on average fuel consumption

Engine efficiency, i.e. an engine's ability to convert energy contained in fuel to motive power, has historically improved. Energy consumption could also be reduced by more than four times with commercially available technology (see Table 2). The question which we have to address in this section is whether improvements in the energy efficiency is likely to result in a decrease in the average fuel consumption of vehicles in Australia, which would warrant changes to the manner in which energy consumption is included in cost-benefit analyses.

Despite considerable improvements in engine efficiency, the average fuel consumption of the Australian car fleet has remained fairly constant since data was first collected in 1963 (Australian Bureau of Statistics, 2007). Rather than lowering fuel expenses, car buyers have therefore taken advantage of improvements in engine efficiency to buy larger and more luxurious (heavier) cars. This meant that energy consumption benefits, which might have been achieved through engine efficiency gains, were offset by increases in engine power.

Australia is not unique in this respect, and the Royal Commission on Environment and Pollution (Fergusson & Skinner, 2002) found that fuel economy of cars sold in Britain worsened during the period after fuel prices peaked in the 1980s. This is even evident in the increasing popularity of hybrid-electric vehicles. Cars such as the Toyota Prius were once the mainstay of the environmentally conscious, but recently makers of luxury sedans and SUVs are capitalising on the technology. Rather than improving the fuel efficiency of small cars, this technology might ultimately become more popular in large vehicles.

Some even argued that oil price shocks and economic recessions contribute to undermine consumers' desire to buy fuel efficient cars in the long term (Mc Carthy, 2007). It is not uncommon for people to counteract sacrifice and deprivation with over indulgence when they get the opportunity.

Figure 4 tracks the average fuel consumption of the Australian vehicle fleet with the voluntary fuel consumption targets for new passenger cars sold in Australia (Scoular, 2004). We should take into account that these targets are an average of vehicles on offer, and is not weighted by those actually sold. The data shows that despite the availability of more fuel efficient vehicles, average fuel consumption per vehicle has not changed.

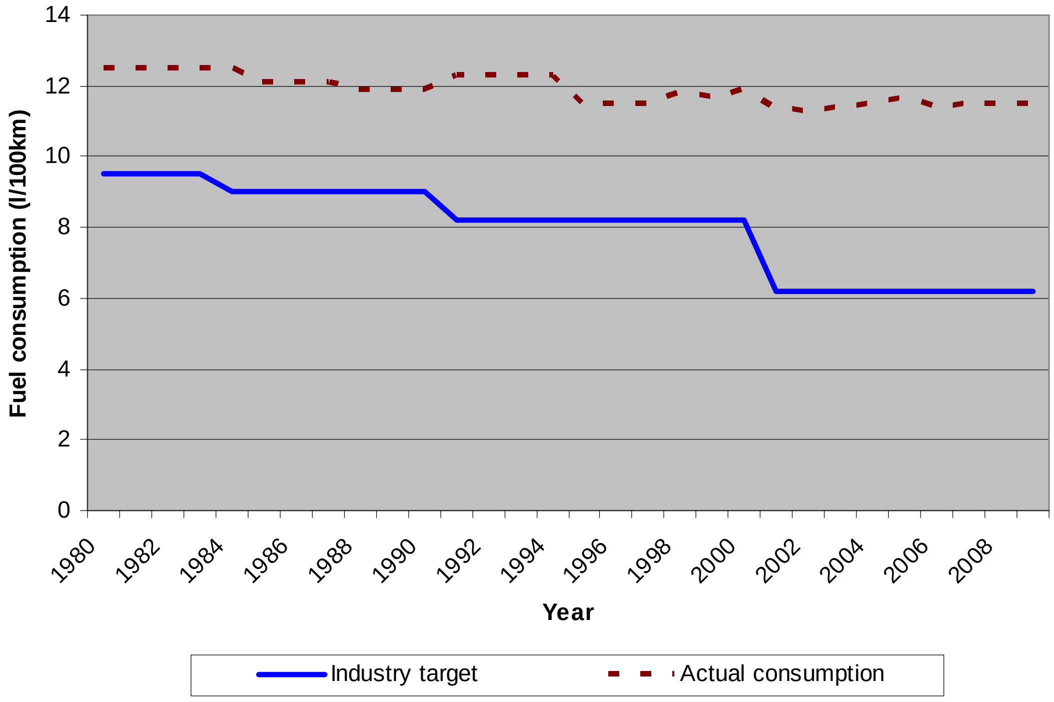

Figure 4 Fuel consumption: Industry target vs. average achieved

From the above assessment it follows that:

- Evaluations in the past correctly assumed that fuel consumption rates would remain static over the evaluation period.

- Industry target of just over six l/100km is almost half of what is currently achieved in practice (see Table 2 above).

- Human behaviour, rather than technological improvements in engine technology, would have the biggest impact on average fuel consumption of fossil fuel powered vehicles. Significant behavioural changes would occur through enforcement (legislation), economic circumstances (significant fuel price increase) and voluntarily (greater awareness of environmental issues).

- Technological improvements would only have a significant effect if it leads to completely new, non fossil fuel based technology.

3. EFFECT OF POTENTIAL CHANGES IN UNIT COST

As pointed out above, an assessment of the impact of alternative vehicle technologies on CBA, should also consider the impact of the unit cost of fuel, GHG emissions and air pollution on fuel consumption related benefits. Sections 3.1 through 3.3 consider the impact on unit price fluctuations on the outcome of our case study CBA.

3.1 Fuel cost

In an economic evaluation, the resource unit price of fuel is expressed in constant prices. Constant prices are, however, only applicable if fuel cost increases at a similar rate to the average long term consumer price index (CPI). If fuel supply decline or remain constant, with a continued increase in demand, the long term change in fuel price would exceed the CPI. This means that unit cost of fuel would have to increase by the difference in long term CPI and the rise in resource cost of fuel.

Although fuel and oil prices have grown faster than CPI over the past four years to mid 2008, Wood & Mokhatab (2007) showed that over most of the past 30 years, international retail petroleum prices kept pace with the CPI in most OECD markets. In future it is, however, expected that major oil exporting nations would expand and diversify their downstream influence through the supply chain as they secure more market share of OECD countries' fuel supply. Combined with this, OECD countries will increasingly be competing for oil with developing economies such as China and India.

In a worse case scenario of high demand and significant supply constraints, the UK Department of Energy and Climate Change (2008) forecast a growth of 50%, in terms of 2008 prices, in oil prices. Under such a scenario, the fuel consumption component of benefits would increase from 26% to 30%, whereas the share of fuel cost in the overall fuel consumption related benefits would increase from 28% to 37%, assuming that fuel consumption remain constant.

However, a drastic change in the unit price of energy would not necessarily lead to an equivalent change in the overall energy consumption cost. As we have seen above, existing vehicle technology offers significant opportunity for lowering the average fuel consumption of vehicles. Past experience showed that consumers have a tendency to adapt to changes in fuel cost, by choosing to buy either larger or smaller cars. It may also affect the diversion rate to public transport in our case study.

Furthermore, the energy unit cost could differ significantly amongst different types of fuel. Although our case study was based on fossil fuel, hydrogen fuel and electric power could potentially be produced from a variety of other sources, including entirely sustainable sources. Changes in vehicle technology, leading to more widespread use of alternative and non-fossil fuel, may alter the unit cost of fuel over a typical 30-year evaluation period.

Allowing for technological changes in the CBA would therefore require much more complex modelling of energy prices, and the effect thereof on fuel consumption, than current standard practice. Future updates of CBA guidelines would have to respond to this need.

3.2 GHG emissions

In the absence of a market mechanism for GHG emissions and air pollution, unit prices for these costs are based on shadow prices. Unit prices impact directly on the perceived importance of technological change on CBA outcomes. To test the effect that unit prices would have on CBA outcomes, we have benchmarked the outcome of our case study based on the Austroads unit price of carbon emissions, with results based on unit prices of other recognised sources.

Austroads' climate change cost is based on avoidance cost estimates in selected countries, including the European Union (AUSTROADS, 2008: Part 4, 28). Values represent the ExternE study which uses a damage cost approach, based on a bottom-up methodology. Table 4 presents the AUSTROADS unit cost in relation to Land Transport NZ (2006: A9-9) and the Stern Review (2007: xvi and 248) values.

Table 4 GHG emission unit cost

	Austroads	Land Transport NZ	Stern Review		
			Current	Discounted BAU	2030 BAU
CO_2 cost per tonne	$48	$24	$38	$107	$455

Notes:
All values in Australian dollars. 1 AUD = 0.79 USD and 1.27 NZD
BAU – business as usual trajectory

Table 4 shows a considerable variation in the shadow price of a commodity which is supposed to have a uniform global price. It is interesting to note that Land Transport NZ's (p A9-9) carbon cost is about half that of Austroads', which means that the value of cost of carbon emissions of total vehicle operating costs is considerably higher than Land Transport NZ's estimates of about 7.5% (2007:A9-9).

The Stern Review, which used top down macro-economic techniques to calculate the discounted cost of carbon emissions, is one of the most widely recognised benchmarks for the value of GHG (Stern, 2008). Although Stern's figure for current levels of atmospheric GHGs is fairly closely aligned with that of AUSTROADS, his business-as-usual (BAU) values are considerably higher than typical numbers provided in other literature. Although Stern's figures have been criticised by, among others, Nordhaus (2007), Dasgupta (2007), Tol (2007) and Jensen & Webster (2007) as being an overvaluation, it nevertheless is worth considering the impact that the higher GHG unit value would have on CBA outcomes.

Stern's view is that, if we continue on a business as usual trajectory, the long term discounted social cost of carbon per tonne would amount to $107 (Stern, 2007: xvi). In 2030 this would be as high as $455 per ton CO_2 (Stern, 2007:248). This increase is due to the escalation of the environmental cost impact of GHGs emissions as the level of GHGs in the atmosphere rise. The marginal cost of releasing a ton of CO_2 at the current atmospheric stock of GHG is much less than releasing the same amount of GHGs 2030. CBA guidelines currently do not take this effect into account.

The implications of this on micro-economic CBA appraisals are that, if we believe that emissions reduction targets would not be met, we need to adjust the unit cost of carbon over the project evaluation period to take account of the deteriorating level of GHGs in the atmosphere. Updating the case study with Stern's social BAU carbon costs, fuel consumption related benefits as a share of total benefits would increase from 26% to 30% at $107 per tonne and 49% at $455 per tonne. GHG emissions' contribution to fuel consumption related benefits would increase from 21% to 37% at $107 per tonne and 72% at $455 per tonne. This would push up the benefits in our case study by more than 6% at $107 per tonne, and by 45% at $455 per tonne).

Technological change could therefore potentially have a much greater impact on total project benefits than currently thought (see Figure 5). Also important is the fact that, unlike fuel unit prices, consumers would not react to higher environmental cost unless they are taxed an equivalent amount for emissions. This means that, unlike fuel price increases, the increase in climate change cost would not necessarily be compensated for by a reduction in specific vehicle emissions as the unit price increases.

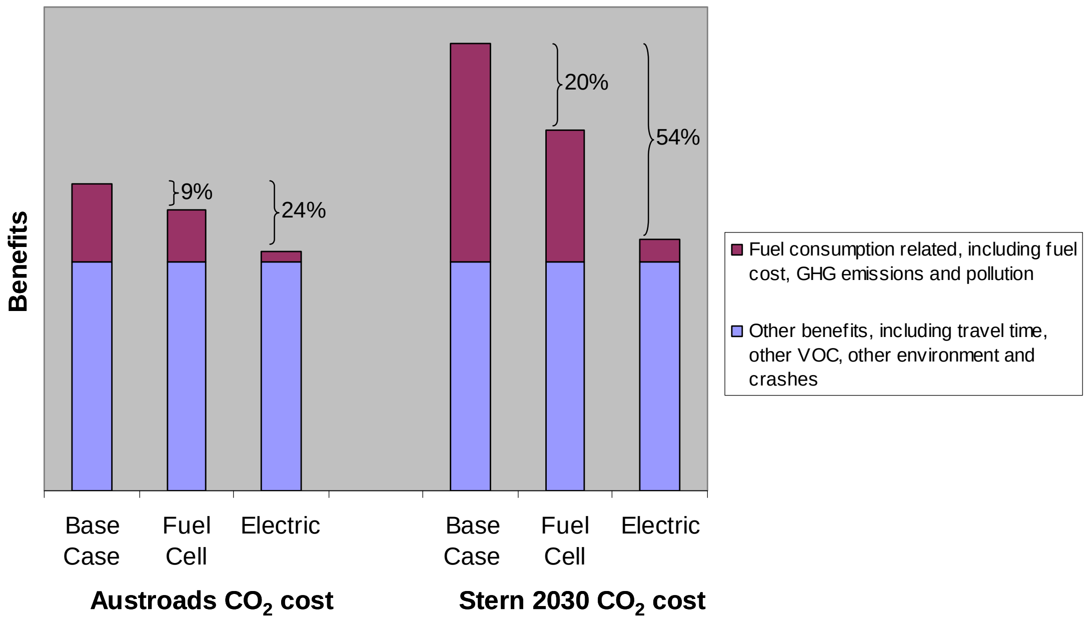

Figure 5 Effect of fuel consumption related benefits on first year benefits

3.3 Air pollution cost

As with GHG, the air pollution unit price is based on shadow prices. However, in the case of air pollution, impacts are of a local, rather than international, nature. Whereas GHG unit costs should be globally uniform, air pollution shadow prices take account of local characteristics such as population density, vehicle occupancy and purchasing power parity.

Although guidelines include "national" urban and rural values, air pollution unit cost is highly dependent on the location where it is emitted. One of the main advantages of technologies such as plug-in electric and hydrogen fuel cell vehicles are that their air pollution could potentially be shifted from high impact areas such as cities, to low impact areas where unit costs would be minimal. There is thus considerable scope for reducing the unit cost of air pollution by introducing alternative technologies.

4. CONCLUSIONS AND WAY FORWARD

4.1 Conclusions

The effect of technological change on economic evaluation results largely depends on the unit value of GHG emissions. Using current unit values from guidelines documents, the effect of technological change on project benefits would be relatively small. However, applying higher values from recent research shows that technological improvements in vehicle technology could potentially have a profound impact on evaluation results.

In the past, CBA models correctly assumed (by default) that average fuel consumption per vehicle, and the unit price of fuel, would remain constant over the project evaluation period. Given that average fuel consumption is dependent on human behaviour, rather than technological improvements, it is likely to remain constant in future if there are no external shocks to dramatically change behaviour. Short spikes in the fuel price are unlikely to have a significant effect on average long term fuel consumption. Historically, consumers were quick to resume habits of buying larger cars when economic conditions improve or fuel price decline.

Technological change would only have a significant effect on average fuel consumption if it involves a cost-effective alternative to the internal combustion engine, and if the fuel could be efficiently manufactured, distributed and stored. However, even if technological changes filter through to the average fuel consumption of new cars, it will take a long time to affect the average consumption of vehicles in use. If alternative fuelled cars become more commonplace, it would be more appropriate to express vehicle energy usage in mega-joules/km (Mj/km), rather than litres/100 km.

4.2 Way forward

This paper demonstrated the need for further research in a number of specific areas, including

- The elasticity of a rise in fuel price on average fuel consumption on the Australian vehicle fleet, given the replacement time lag.

- Work towards international standards for carbon unit prices, and requirements for sensitivity tests with higher and lower values.

- Need for national standards for calculating energy consumption (rather than fuel consumption) to take account of possible changes in the vehicle fleet.

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