Alternative Transport Fuels

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Abstract:

Alternative fuels have the potential to reduce greenhouse gas emissions from transport, and to reduce urban air pollution and noise. This paper reviews recent research findings on emissions from these fuels, as well as safety, costs and other aspects relating to both vehicles and fuels, which influence market acceptance. New motor vehicle technology optimised to account for the characteristics of each fuel would need to be implemented to achieve maximum benefit. The effects of taxes and charges on fuel price are noted. The paper emphasises that any decision about whether to promote or encourage the take-up of alternative fuels is rendered extremely difficult in the environment of changing technology, changing vehicle emission standards, developments in gasoline vehicle fuel efficiency, and the effect of these on new vehicle costs.

The views expressed in this paper are those of the authors, and do not necessarily represent those of the Bureau of Transport and Communications Economics.

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Introduction

This paper reviews the potential for the introduction of 'new' fuels in road transport, and the effects this would have on greenhouse gas emissions and local air pollution. If alternative fuels (A/Fs) are to be widely used, they must be technically feasible, cost competitive (taking taxes and charges into account), and be accepted by the market. Cost competitiveness will be influenced, in part, by the extent to which the environmental costs of burning various fuels are incorporated into their respective market prices. Failure to charge fully for environmental and other costs resulting from fuel use will result in the 'wrong' fuels being bought. It is also likely that lack of knowledge about A/F options may preclude optimum market outcomes.

Use of A/Fs has implications beyond the environmental effects: reduced reliance on petroleum-based fuels would improve Australia's energy security, and there would be balance of payments effects given that domestically sourced A/Fs could replace imported oil and petroleum products, and perhaps generate exports of fuels and A/F technology. However, wider use of A/Fs would need to overcome the barrier presented by the existing infrastructure for petroleum-based fuels, and would not be easy.

Reformulated gasoline

Reformulated petrol is being developed for the North American market because of supply factors important. About two-thirds of Australia's LPG supply is recover conversion costs would be more than the price competitive (taking taxes and charges into account), and be accepted by the market. Cost competitiveness will be influenced, in part, by the extent to which the environmental costs of burning various fuels are incorporated into their respective market prices. Failure to charge fully for environmental and other costs resulting from fuel use will result in the 'wrong' fuels being bought. It is also likely that lack of knowledge about A/F options may preclude optimum market outcomes.

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Reformatual gasoline

Reformulated petrol is being developed for the North American market because of 30% in 2005 (ABARE 1991). Since engine technology and refuelling infrastructure already exist for LPG, and given a short payback period, why is there not greater use of this alternative?

Though there is a large number of auto LPG outlets in Australia, there is poor availability in remote areas. Also, gas conversion of vehicles results in reduced range (with a similar size tank), power (about 3-4% for a Commodore or Falcon ([Caldwell 1989]) and boot space (a particular problem for small cars). The average time to recover conversion costs would be more than three years for vehicles with a low rate of fuel consumption or low annual VKT. Perhaps more importantly, the price advantage of LPG over petrol is not guaranteed: it relies on the Federal Government's not imposing sales tax or excise on LPG, or removing excise from petrol or diesel. At current oil prices, if LPG incurred an excise charge equivalent to that of petrol (in cents per litre), its operating cost advantage would be negated. A price advantage would remain, however, if externalities were costed and included in fuel prices.

The IEA (1992) estimates that the full fuel cycle greenhouse emissions from automotive LPG (a propane/butane blend) are 15% below those of petrol. Wilkenfeld (1991) estimates 18%. Urban emissions of CO are around half those from gasoline. HC and NO\(_x\) emissions are similar to those from gasoline. Sergeant (1991) advocates an increased role for LPG, perhaps more than doubling current LPG vehicle use. He suggests that affordable original equipment manufacture vehicles are needed to increase the viability of LPG (yet an LPG car introduced into Australia some years ago was not a commercial success). Doubling the penetration of LPG vehicles would lower current total transport greenhouse emissions by around 0.3%, and urban noxious emissions by roughly 1%.

Supply factors are important. About two-thirds of Australia's LPG supply is recovered during oil and natural gas production, the rest from oil refining. Australian production of naturally occurring LPG is forecast to decline over the years (reserves are 45 years at current annual production rates) and to meet domestic demand for all uses, LPG imports are projected to increase substantially (ABARE 1991). The scope for saving emissions by switching LPG from other uses to cars needs to be explored, but is likely to be limited. Importing LPG could be a possibility, but the transport costs would add around 20% to the fob price (about 7% to the retail price).

Diesel

Wilkenfeld (1991) has estimated total greenhouse gas emissions from cars in grams of CO\(_x\) equivalent per km as 201 for diesel and 241 for petrol, on a full fuel cycle basis (emissions from oil well to tailpipe). For light duty vehicles (LDVs), the IEA (1992) estimates that diesel vehicles will have a greenhouse emissions advantage of 18.7% in North America and 20.2% in Europe in 2005, compared to a vehicle using reformulated petrol (full-fuel-cycle basis, including a factor accounting for the longer average lifetime of a diesel engine). This is similar to Wilkenfeld's results.

The IEA (1992) notes that since a fair proportion of the greenhouse advantage of diesel arises from lower relative emissions of hydrocarbons (HC) and oxides of nitrogen (NO\(_x\)). Full fuel cycle greenhouse emissions per kilometre from reformulated petrol (full-fuel-cycle basis, including a factor accounting for the longer average lifetime of a diesel engine (800 years on a conversion cost of $2000 at average car utilisation rates (Haley 1990)). The rate of growth in LPG use in road transport has been high over the past decade (18% pa), but LPG currently accounts for only 2.5% of road transport energy use, and it is expected to account for only 3% in 2005 (ABARE 1991). Since engine technology and refuelling infrastructure already exist for LPG, and given a short payback period, why is there not greater use of this alternative?

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regulations for petrol-powered cars would reduce this advantage significantly. In terms of CO₂, the IEA estimates only an 8% advantage for diesel (Wilkenfeld derives 7%).

Considering urban emissions, a new diesel car would have over 60% lower CO₂ and HC emissions than a comparable gasoline vehicle (IEA 1992), but particulate emissions are a growing health concern. The Advisory Committee on Vehicle Emissions and Noise (ACVEN) is currently investigating standards for particulates, CO₂, HC, and NOₓ for diesel LDVs and trucks. Though these will not apply to diesel passenger cars, if use of these cars were to increase, their particulate emissions would have to be considered. Progressively tighter constraints on particulate emissions from diesels would eventually result in a more energy-intensive diesel fuel production process, with a consequent lowering of diesel's greenhouse advantage.

Stricter emission standards for vehicles could be expected to influence vehicle costs and total emissions from different fuels, taking into account the greenhouse impact of stricter standards on vehicle fuel efficiency. It is clearly difficult to predict the future emissions rankings, let alone the effects on vehicle costs.

Refinery configurations and feedstocks constrain the output of diesel (and LPG) in Australia, and therefore the substitution potential, of diesel for gasoline (NSWDME 1990). Demand for diesel is projected to increase by some 70% in road transport from 1988 to 2005 (ABARE 1991), so that making diesel available for LDVs may require the substitution of CNG or alcohol fuels for diesel in heavy vehicles. Scope for this may be limited, unless actively supported by government policy. Using the natural gas directly in LDVs would seem a preferable option, especially as there are major health concerns over particulate emissions, which are primarily from diesels. For this reason, importing diesel may not be warranted, even if the economics were favourable.

**Alcohol fuels: ethanol and methanol**

Ethanol or methanol can replace petrol as pure ethanol (E100) or methanol (M100), can be used in blends of 3 to 90% alcohol with gasoline, or can be combined with isobutylene to form MTBE or ethyl tertiary butyl ether (RTBE). These act as octane enhancers and as oxygenates reducing CO emissions in vehicle exhausts (OTA 1990).

Use of ethanol as a diesel substitute is at an early stage of development (NSWDME 1990). Alcohols can be used as diesel fuel extenders or, with extensive engine adaptations, in larger proportions (IEA 1990). Demonstrations of alcohol fuels in buses and/or trucks are being conducted in Canada, Germany, Japan, Sweden, NZ and the US (IEA 1990). In Australia, APACE Research Ltd has developed an ethanol and diesel emulsion (diesohol) which, if the emulsion contains less than 25% ethanol, can be used in unmodified diesel engines. An unmodified Mack truck using diesohol (15% ethanol) had the lowest 'greenhouse gas index' in the 1992 Energy Challenge.

Ethanol is currently manufactured from biomass, via fermentation of sugars. In laboratories it has been made from lignocellulosic fractions of crops. Ethanol can also be made from petroleum and natural gas. Methanol can be produced from biomass, natural gas or coal, but with widely varying full cycle greenhouse gas emissions.

**Vehicle technology**

In current technology gasoline engines, alcohol blends of up to 10% seem to be a feasible option, though even these will cause some drivability problems -vapour lock, and in older vehicles, deterioration of fuel system components, including clogging of the fuel filter (NSWDME 1990). High alcohol content fuels are not suited to retrofitted vehicle programs. Higher cost new technology vehicles will be required if fuels with higher alcohol content or pure alcohol are to be used. These vehicles could be optimised to the fuels' combustion characteristics to provide greater efficiency and emission benefits. High alcohol content fuels can contaminate engine oils causing corrosion of engine components, especially on cold starts and short trips. Starting difficulties in cold conditions may also be experienced. A blend with 15% gasoline would help, although further work on cold starting is still required. Control of aldehyde emissions is also needed.

Flexible or variable fuelled vehicles (VFVs) have been developed to assist the transition from gasoline to alcohol fuels. VFVs sense the fuel blend in use and automatically adjust the engine to run on any combination of fuel. VFVs share some of the problems of single-fuel vehicles, as well as having some of their own. Formulation of suitable lubricating oils may be more complex. Emission certification would be required for the full range of fuels used and catalysts would need to be effective over a wide range of exhaust compositions (Magasanik et al 1990). VFVs are more complex and costly, and VFV engines cannot be optimised for alcohol fuels.

**Emission of greenhouse gases**

The potential of methanol or ethanol fuels to reduce greenhouse gas emissions is dependent on the source of the feedstock (Table 1), as well as vehicle technology. With biomass feedstock, CO₂ produced during combustion is re-absorbed from the atmosphere during plant growth, although some additional CO₂ emissions arise from farming and processing the crop (Watson 1991). Emissions depend on the crop grown, the process fuel and release of greenhouse gases from the soil above natural levels.

Also, special energy crops may simply replace existing CO₂ absorbing plant biomass. Production of ethanol from lignocellulose via technologies currently under development will be needed if significant greenhouse gas emission improvements are to be achieved relative to gasoline fuel. Ethanol from corn fields (as in the US) using coal generated electricity for processing will not improve emissions. Denitrification of fertilisers applied to the crop can also contribute to emissions (Sterling and De Luchi 1991).

Methanol from natural gas (the most cost effective source) provides at most a 3% reduction in greenhouse gas emissions over gasoline in present technology vehicles. In Australia, Watson (1991) has suggested that mandatory implementation of M85 fuel (from gas) in the year 2000, could by the year 2015 achieve a 5% reduction in greenhouse gas emissions from the vehicle fleet assuming some of the vehicles would be optimised to the combustion characteristics of the fuel.

**Noxious emissions**

In urban areas the principal pollutants from motor vehicles include CO, sulphur dioxide, NOx, HC, particulates and lead. The effect of alcohol fuels on exhaust emissions of non-greenhouse gases relative to gasoline is mixed, often situation specific and influenced by the state of prototype development. Increasing the alcohol content of the fuel, under most circumstances, will result in reductions of CO, aromatic compounds, SO₂, and in diesel vehicles, particulates, while aldehyde and alcohol emissions increase. Any change in atmospheric effects from the use of VFVs...
Table 1: Greenhouse gas emissions for light and heavy duty vehicles using M100 or E100 relative to reformulated gasoline and diesel fuels.

<table>
<thead>
<tr>
<th>Fuel type and source</th>
<th>Percentage change in life-cycle emissions (grams per km CO₂ equivalent)</th>
<th>Present¹</th>
<th>Future²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LDV¹</td>
<td>HDV¹</td>
<td>LDV²</td>
</tr>
<tr>
<td>Ethanol, lignocellulose³</td>
<td>-72.6</td>
<td>-71.3</td>
<td>-73.1</td>
</tr>
<tr>
<td>Ethanol, corn with coal</td>
<td>31.8</td>
<td>68.0</td>
<td>19.9</td>
</tr>
<tr>
<td>Methanol, natural gas</td>
<td>-2.8</td>
<td>15.5</td>
<td>-11.4</td>
</tr>
<tr>
<td>Methanol, coal</td>
<td>58.7</td>
<td>96.3</td>
<td>na</td>
</tr>
<tr>
<td>Methanol, lignocellulose³</td>
<td>-18.4</td>
<td>2.1</td>
<td>-60.0</td>
</tr>
</tbody>
</table>

Notes:
- a. Time horizon of 100 years
- b. Present refers to current technology vehicle.
- c. Future refers to high efficiency vehicles optimised for alcohol fuel.
- d. LDV, light duty vehicle, gasoline fuel.
- e. HDV, heavy duty vehicle, diesel fuel.
- f. Lignocellulose from plantation forest or plant residue.

Source: Sperling and De Luchi (1991)

The table shows the percentage change in greenhouse gas emissions for both light (LDV) and heavy duty (HDV) vehicles using M100 or E100 relative to reformulated gasoline and diesel fuels. The emissions are given in grams per kilometre of CO₂ equivalent. The present technology vehicle emissions are compared to the future high efficiency vehicles optimised for alcohol fuel.

Costs:

Vehicle costs: Magasanik et al. (1990) estimated increased production costs of between $500 to $2000 for VFVs. Because ethanol is less corrosive than methanol the incremental cost to vehicle production costs would be less than for methanol.

Fuel production costs: To be cost competitive, large-scale production from lignocellulose from the technologies currently under development will be necessary.
In Australia, natural gas would be the most economically feasible option for methanol production. A NSW DME (1990) consultancy study estimated costs of methanol produced from pipeline gas at 33 to 44 cents per LGE at Sydney, Wollongong or Newcastle (a world scale plant producing 2500 tonnes per day). Methanol imported to the Sydney region from Dampier using NSW Shelf gas was costing at 33 to 44 cents per LGE (4 world scale conventional plants producing 10,000 tonnes per day in total). Costs given in the study are influenced by projected natural gas and technology costs, and it is not known at this stage whether larger scale production would lower costs. Methanol imported by tanker from overseas was assessed at costing 33 to 39 cents per LGE.

Costs of distribution: Difficulties with the distribution of neat ethanol or ethanol blends, arising primarily from the solvency effects of ethanol and ethanol’s affinity for water, may mean additional distribution costs. If ethanol were distributed via the existing gasoline system there would be the potential for water contamination throughout the entire process (NSW DME 1990). Ethanol can dissolve accumulated substances in pipelines, storage tanks and other components of the distribution system that are insoluble in petrol (NSW DME 1990), leading to impurities in the fuel.

Methanol is water soluble and corrosive to some materials currently used in present distribution systems (OTA 1990), and has only half the energy content of gasoline thus requiring more transport infrastructure to move an equivalent (on an energy basis) amount of fuel. It is possible that the current infrastructure of pipelines, storage tanks and road tankers may not be compatible with methanol, and that extensive duplication or modification of existing equipment would therefore be required (OTA 1990).

Safety

The safe use of alcohol fuels will require the incorporation of denaturants to deter deliberate human ingestion, and substances to make the flames from alcohol fires more visible, as well as a public education programme and training for people who regularly handle alcohol fuels. Accidental ingestion could be reduced by fitting anti-siphoning devices to fuel tanks.

Natural gas

Natural gas may be used as a transport fuel in either compressed or liquified form (CNG or LNG). Natural gas vehicle (NGV) technology is fairly well developed, and development is proceeding on a wide front in Australia and elsewhere. Natural gas is already available in large quantities in Australia, and the backbone of a distribution system is in place. Australia’s known gas reserves contained almost 4 times the energy content of its oil reserves in 1988. DPIE (1991) estimated that natural gas reserves exceeded 50 years at 1991 production levels.

The Australian Gas Association (AGA) has developed its '10/03/35' plan for NGVs. This strategy involves reaching a target of 10% penetration of fuel sales for road vehicles (or about 340,000 NGVs) in 10 years, at a 'pump' price of 35 cents per cubic metre. In energy content, a cubic metre is equivalent to 1.09 litres of petrol or 0.98 litres of diesel. In Australia, initial interest in NGVs has been directed to replacing diesel-powered depot-based buses and trucks with dedicated NGVs. NIEIR (1988) estimated that use of NGVs could replace about 2,500 ML of oil in 2003 valued at some $700m (in 1987 dollars), under a scenario involving about one-sixth more vehicles than the AGA 10/03/35 plan. By comparison, in 1987-88 Australia imported about 13,000 ML of crude oil, other refinery feedstocks and petroleum products, and exported about 9000 ML.

Emissions

Widespread use of NGVs could have significant environmental implications: globally in terms of greenhouse gas emissions; and locally, in terms of air pollution and vehicle noise in urban areas. Wilkenfeld (1991) estimated full fuel cycle greenhouse emissions for cars, in grams of CO₂ equivalents per km, of 200 for CNG, 201 for diesel and 241 for petrol. For LDVs, the IEA (1991) estimated that, while CNG had lower tailpipe emissions than either petrol (by 18%) or diesel (by 10%), greenhouse emissions from fuel production, distribution, compression and vehicle manufacture negated the greenhouse advantage over diesel. An advantage of about 15% over petrol remained. In heavy vehicles, Wilkenfeld (1991, 142, 143) concluded: 'The heavy vehicle market segments where NGV penetration is most cost effective are those where it will make the least difference to greenhouse emissions...there would be very little reduction in greenhouse gas emissions from converting the heavy vehicle market from diesel to CNG or LNG...'.

The AGA (1990, p182) stated that there appeared to be no significant greenhouse advantage in replacing diesel with natural gas.

The Victorian Gas and Fuel Corporation (VGFC) considers that for NGVs to have a significant effect on greenhouse emissions, they would have to penetrate the car fuel market (VGFC 1991 personal communication). Otherwise, the main environmental effects would be on local air quality and noise from use in trucks and buses. NGVs have the potential to reduce certain noxious emissions significantly, such as oxides of sulphur (from imported crudes), HCs (hence photochemical ozone and smog) and particulates. NOx emissions may be similar to those from petrol.

Methane, the principal component of natural gas, has a radiative forcing greenhouse effect about 16.5 times that of CO₂, by weight (Pearman 1989). If there were to be significant fugitive losses, this would greatly reduce (or negate) the advantage which NGVs could yield in terms of tailpipe emissions. The VGFC considers that fugitive losses are concentrated in the old town-gas reticulation systems, with effectively no fugitive losses from new lines to natural gas refuelling stations.

Practicality of NGVs

Major concerns about the practicality of NGVs are their limited range and the availability of refuelling facilities. Space, weight and cylinder/ranke cost limitations preclude fitting the gas capacity required to match the range of petrol or diesel vehicles. Loss of power and carrying capacity, as well as refuelling times and availability of service facilities are also factors to be considered. With suitable design and installation standards, safety should not be a major concern. Safety devices are available to prevent cylinders from exploding. Merz (1991) considers that, although there are only limited data, natural gas has a good safety record.

The car of today, if converted to natural gas/petrol dual fuel use would be less efficient than a purpose-designed natural gas engined vehicle. A future car would be designed primarily as an NGV, but with a secondary ability to use petrol in a 'limp home' mode. If for greenhouse reasons it were decided to encourage the widespread use of NG cars, then it would seem desirable to encourage their manufacture, vehicle
conversions being less efficient than purpose-designed NGV engines. The International Association for Natural Gas Vehicles (IANGV 1990) suggests that the range of a 1.6 litre car will be about 160 km with a 60 litre cylinder, (dual fuel), or about 380 km, (dedicated NGVs), with two 60 litre cylinders, about three-quarters of the range on petrol. One operator of NGV taxis undergoing trial in Goulburn found range a problem and has since reverted to LPG fuel (1992 personal communication).

Engines in NGV trucks and buses may be either dual-fuelled. diesel engines using natural gas, or NGV engines using spark ignition and running solely on natural gas. Dual fuel engines in buses have achieved up to 95% gas substitution for diesel at high loads; in trucks, about 80 to 85%. Gas substitution at idle is zero, and increases with load, the overall average for trucks being about 60% (Yorke 1991). Yorke (1991) considers that the state of development of spark ignition engines for natural gas is two to three years behind that for buses, in part because of the greater complexity of truck engines, with turbochargers and aftercooling now normal. Merz (1991) points out that microprocessor engine management systems, now common on cars, are only beginning to be considered for trucks. Spark ignition engines are generally 5% better than overseas engine designs (Clifford 1991). Lean burn engines will emit less NOx, HCs and CO, and should be available by 1993.

A 'chicken and egg' or 'VHS/Beta' problem arises: given the limited range of NGVs, and the cost and refuelling times of home refuelling appliances, there may not be significant penetration of the light vehicle market with an artisanal NGV truck with a range of 775km, which would reduce payload if trucks are customarily operated close to axle load limits. NGV costs

Investment in CNG refuelling facilities for the general public would require assurance of significant penetration of the car, taxi and light commercial vehicle market. Cars, on average, perform low annual kilometres compared to commercial vehicles, and acceptable payback periods on conversion expenses for most light vehicles may rely on continued exemption from excise or other taxes. A 'chicken and egg' or 'VHS/Beta' problem arises: given the limited range of NGVs, and the cost and refuelling times of home refuelling appliances, there may not be significant penetration of the light vehicle market until a network of public refuelling facilities exists. The VGFC considers that to make a significant penetration of the car market, there would need to be 400 NGV refuelling stations in Victoria alone (VGFC 1991 personal communication). The AGL sees home refuelling as making better use of the reclamation infrastructure. The average vehicle would use around 90GJ per year: average NSW household use is about 20GJ per year.

The VGFC has introduced a series of fully self-contained modular NGV fuelling stations for depots. The VGFC and AGL are investigating introducing NGVs into line-haul trucking in Australian inter-city corridors. Acceptable payback periods on conversion costs (less than 2 years, according to Gafcor (1988), or 3 years on average according to costs (less than 2 years, according to Gafcor (1988), or 3 years on average according to Cuthbertson, Kelso and Thomas 1991) are available for buses using gas supplied at industrial rates from depots (NIEIR 1988) and for articulated trucks using gas supplied at the 1010/235 price and travelling typical distances per year (NELA 1991). For rigid trucks only large high-mileage units might be converted.

Electric vehicles (EVs)

Recent development of EVs has been spurred on by the 1990 California Air Resources Board regulations, developed in response to the deterioration in urban air quality due to internal combustion engine motor vehicles. These regulations require that 2% of new cars and light trucks sold in 1998 must be zero-emission vehicles (ZEVs), growing to 10% in 2003. This would provide a market for over 120 000 EVs in 2003. Some other US states have announced that they will adopt the Californian ZEV program (Parcell 1992). Current research is aimed at increasing the electric vehicle's limited range by improving battery storage capacity, battery life, motor and drive efficiencies, and reducing vehicle drag, rolling resistance and weight.

Batteries

Table 3 shows battery energy densities (of which vehicle range is a function) and power densities (of which acceleration and hill-climbing are functions). Rand (1992) in surveying battery types for EVs concluded that the lead-acid battery was the obvious, if not the only battery for medium-term, large-scale production. An international consortium has recently been established to develop an advanced lead-acid battery for the EV market, with a target energy density of 50 watt-hr/kg (Deshpande 1992). The nickel-iron battery is seen by some as the viable next step beyond the lead-acid battery, and is to be used by Chrysler in its EPIC commuter and TEVan (AEVA 1992). Nickel-cadmium (Ni-Cad) batteries are used by Nissan in its FEV car, fully rechargeable in 15 minutes, and in the Japanese IZ4, for which is claimed a range of 548km at a steady 40kph (Ishitani 1992). Fiat's Panda Elettra gives 30% better range in city use with Ni-Cad batteries than with lead-acid batteries (Rand 1992), although at a significantly higher cost. However Rand (1992) considers that cadmium-based systems should not be considered on environmental grounds due to disposal problems of highly toxic cadmium. Matsushita has developed a nickel-hydride battery vehicle for which it claims 2.8 times the range given by lead-acid batteries. BMW's E2 car, planned for sale in California by 2003, uses sodium-sulphur batteries, as does Ford's Ghia Conecta. An international consortium (ALABC, the Advanced Lead-Acid Battery Consortium) has recently been established to develop an advanced lead-acid battery for the EV market (Deshpande 1992). In the US, the Advanced Battery Consortium (funded jointly by the US Dept of the Environment, carmakers, electricity companies and battery makers) is to investigate three or four battery types. These may include sodium-sulphur, lithium-aluminium/iron-sulphide, zinc-air and lithium polymer (AEVA 1992).

Hybrid powerplants, such as a constant speed internal combustion engine (perhaps running on an A/F) could be used to recharge the vehicle's batteries while driving or to supply power directly during extended running. GM has developed the HX3 petrol/electric concept car, while Volkswagen have a hybrid diesel/electric vehicle under test. Solar panels mounted on a vehicle (such as on Ford's Ghia Conecta, planned for production in the UK this year) could partially recharge the batteries during the day.
Comparisons between electric and petrol vehicles using energy consumed per tonnekilometre of freight (tkm), or per passenger kilometre (pkm) may be more appropriate. Unfortunately these data are usually not available for EVs. Gosden (1990) averaged the specific energy consumption of five EVs (four vans and one passenger car) to arrive at a specific energy consumption of 131 Wh/km, using electricity producing 1080g CO\(_2\)/kWh as supplied to the consumer. From these data, based on currently available technology, an EV would produce 141g CO\(_2\)/tkm. A 1,000kg petrol vehicle generating at the tail pipe 2.4 kg CO\(_2\) per litre (L) of fuel consumed would need to consume under 5.9 L/100 km to have lower greenhouse emissions than Gosden’s (1990) average EV.

The GM Impact EV is currently a state of the art vehicle design, powered by sealed lead-acid batteries, and incorporating advanced aerodynamic and structural design features, and low rolling resistance tyres. Gosden (1990) estimated the Impact to have a specific energy consumption of 81 Wh/km at a constant 96 kph, giving a CO\(_2\) emission of 87 gm/tkm using Australia’s power supply mix, equivalent to a petrol car with an average fuel economy of 3.6 L/100 km. However, GM has produced a petrol-engined concept car, the Ultralite, which has a claimed highway cycle consumption of only 2.9 L/100km. No vehicles now on the Australian market incorporate the advanced body and tyre design features of the Impact or the Ultralite. Nevertheless, the Daihatsu Charade and Suzuki Swift can average 4.6 L/100 km for the highway cycle (DPJE 1990). The Charade and Swift have twice the range of the Impact, which seats only two adults.

In urban areas, the natural areas of operations for EVs, advanced purpose-designed EVs like the Impact may produce less CO\(_2\) emissions (93g/km) than advanced petrol-powered cars (Ultralite is 119g/km). While the Impact is only a 2-seater, and its emissions per seat-km are higher than those of the 4-seat Ultralite, the average occupancy of a car on the journey to work is only 1.2 persons (BTCE 1991), and the emissions per actual passenger-km might still be lower than those of the Ultralite.

Gosden (1990) compared CO\(_2\) emissions from EVs and NGVs, concluding that if natural gas was to be used to generate electricity, CO\(_2\) emissions would be 27% lower from an EV than from an NGV. However using electricity from the Australian power station mix to supply EVs, it appears that CO\(_2\) emissions would be considerably higher from current EV conversions than from NGVs, but for ‘state of the art’ EVs (eg Impact), they could be 20% lower.

Emissions of noxious gases and safety of electric vehicles

Noxious emissions due to EVs arise from electric power generation. The impact of these emissions would be mostly in the area near the power station and areas down wind of the smoke stack. Emissions also arise from battery manufacture. Shifting pollution from a diffuse source (many moving motor vehicles) to a point source (power station) may facilitate implementation of pollution controls.

Rajan et al (1989) list four safety concerns relating to the operation of EVs which will need to be addressed. These are: release of poisonous gases, hydrogen explosions, sulphuric acid burns and electric shock. The severity of each of these factors depends on the type and design of battery, and the electrical safety measures employed. Gaseous emissions and their effects are reduced by correct battery charging procedures and adequate ventilation (Rajan et al 1989). Safety in an accident or under abnormal battery operation is a particular concern with sodium/sulphur batteries. Major concerns are sodium fires, sodium/water explosions and a runaway sodium/sulphur reaction (Rajan et al 1989), each of which can produce toxic gases and other byproducts (Siodolfsky 1989).
Production, use and disposal of the vehicle's batteries raise environmental and health issues. Lead from lead/acid batteries is likely to be salvaged: additional lead production with the introduction of EVs will mostly be for the initial batteries used in the vehicles. There may be some increase in emissions of lead and associated metals such as cadmium from mining and manufacturing (Rajan et al 1989).

Electric vehicle costs.

The initial purchase price of EVs may be high, due largely to low production volumes: for example, the Fiat Panda Elettra, with a production target of 1000 in 1992, is priced, in Italy, at between 73% and 225% above Panda petrol models (Rogers 1991). The Australian Huntington Mira conversion has a quoted price of $16,000 plus sales tax, about twice the price of the petrol Mira. There is also the cost of replacing batteries every two to four years. For example, replacement of the battery pack for the Impact has been stated to cost about US$1500 every three years. Some schemes have proposed battery leasing arrangements, spreading the cost over the life of the batteries.

The high initial cost of EVs, which in mass production may be 25-50% above the cost of petrol versions, may to some extent be offset by a longer vehicle life and lower maintenance relative to internal combustion engine vehicles. However while the running costs (including battery costs) of EVs are likely to be substantially less than for petrol cars, a very rough comparison of the Daihatsu Mira and the Huntington Mira EV suggests that the simple pay-back period on the additional capital outlay for the EV would range from 16 years (100% extra cost and 15,000 km pa) to 27 years (100% add-on and 10,000 km pa).

Hydrogen

In the longer-term, hydrogen may become a viable transport fuel, either as a fuel for internal combustion engines, or in fuel cells. The IEA (1992) regards hydrogen only as a long term possibility, and hydrogen fuel cells as a very long term possibility. However, the IEA (1992) points out that, by adding 5% hydrogen to natural gas ("hythane"), the level of methane, NOx and CO tailpipe emissions from NGVs could be reduced to levels low enough to meet the California Air Resources Board Ultra-Low Emission Vehicle standards. Were this standard to be adopted in Australia, an approximate calculation suggests that such a reduction in urban emissions could be achieved at a cost of an extra 7% on the natural gas price, based on a recent US price estimate for hydrogen produced by hydrolysis using hydro-electricity.

Carmakers have been experimenting with hydrogen-fuelled internal combustion engine vehicles for some time. Recent demonstration projects include a BMW hydrogen powered car as part of a German project to examine the potential for hydrogen produced by solar-voltaic electricity. Mazda is developing a hydrogen rotary engine as the company's primary alternative energy powerplant, but sees it as an option for the 21st century, with the electric car as the more feasible short term option (AEVA 1999). The fuel tank of a liquid-hydrogen powered vehicle would, for the same range, need to have about 4 times the volume of a petrol tank, due to hydrogen's low energy storage density. The energy needed to produce hydrogen fuel in Australia at present, would result in more greenhouse emissions than petrol or diesel fuel use, although the vehicle itself would be 'clean', with no tailpipe CO2 emissions, although some NOx and N2O are produced by the high combustion temperatures (IEA 1992). Only if hydrogen were produced using electricity derived from other than fossil fuels could it contribute to reducing greenhouse emissions, although pressure for low emission cars for urban use, especially in the USA, could encourage production of hydrogen cars. The IEA (1992) estimates that hydrogen produced using nuclear electricity could have full fuel cycle emissions 71% below those of a petrol light duty vehicle in the North American market. Deluchi et al (1988) considered that hydrogen would be produced by electrolysis only where the electricity was produced from non-fossil fuels. Fossil fuels would not be used to generate electricity to produce hydrogen by electrolysis: it would be cheaper and more efficient to produce hydrogen directly from the fossil fuel by gasification of coal or steam-reforming of natural gas. However, Deluchi et al estimated that hydrogen produced from coal gasification would result in 100% more greenhouse emissions than petroleum fuels when used in hydride form, and 143% when used as liquid hydrogen, and regard hydrogen as the least promising of the AF in the short term (Deluchi et al 1986).

Market acceptance of alternative fuels

Market acceptance of alternative fuel vehicles (AFVs) will be influenced by costs and vehicle performance, driving range, fuel availability, refuelling time and safety. The financial viability of an AFV will depend on whether costs of conversion (or additional purchase price), possible lower resale value, any additional maintenance or repair costs, and costs imposed by shorter range, more frequent refuelling and reduced payload, can be recovered in an acceptable time through lower fuel costs. Potential governmental actions in pursuit of cost recovery may also create uncertainty in the minds of potential AFV buyers.

Vehicle production costs are currently higher than for gasoline equivalents for NGVs, EVs, hydrogen, and for vehicles which run on a fuel with a major alcohol component. Operating range for these vehicles is much less than for a gasoline equivalent, unless a major sacrifice in carrying capacity is made. AFVs that can switch to using gasoline, and for vehicle users the range limitation of AFVs is likely to be a major constraint on acceptance of AFVs. Commercial production of batteries with much higher energy densities than current lead-acid batteries may result in a range for EVs closer to that for petrol vehicles. Delivery vehicles with trips of low cumulative daily distances, which can be refuelled overnight, have the greatest short-term potential for natural gas or electricity. Households with more than one vehicle may be able to choose an AFV, especially where the 'second car' is mainly used for short distance trips. However, the second car is often older than the fleet average, and has a low resale value. To replace this vehicle with an AFV may entail an unacceptable outlay for some consumers. Modern petrol vehicles provide a very flexible form of travel: use of an AFV requires far more forethought, particularly if vehicle range is low or fuel stations are infrequent. Uncertainty about the availability and adequate distribution of AFVs, and about the plans of vehicle manufacturers to produce AFVs, will deter consumers from switching to AFVs.
The scope for recouping any costs associated with AFs through lower fuel prices depends, perhaps crucially, on policy on fuel taxation: currently only gasoline, aviation gasoline and diesel (automotive, industrial and marine) fuel oil carry excise. A review (Butcher 1990) of the Inter-State Commission report on road user charges (ISC 1990) recommended that vehicles powered by LPG or other AFs should pay the same road track charges per vehicle kilometre as vehicles using petrol or diesel, and pay essentially the same externality charges for noise (EVs were not considered, and CNG vehicles would also be quieter), although for air pollution, externality charges would vary with the fuel concerned. However, there appears to be a commitment from the July 1991 Special Premiers’ Conference not to tax AFs at this stage. Were the existing system of fuel excises to be extended, in the future, to AFs these fuels may warrant a lesser rate of tax than diesel or petrol, because of environmental advantages. However, even a lower level of government charges would have a severe impact on the viability of NGVs. The AGA has stated that the imposition of taxes on NGVs would “effectively kill” the NGV industry, although it appears that high mileage heavy vehicles might still be financially viable. Taxes on ethanol and methanol fuels would have a similar effect unless the potential of new technologies is realised and production costs decrease considerably.

Uncertainty about the availability, distribution and long-term excise treatment of AFs, and about the plans of vehicle manufacturers to produce AFVs, will deter consumers from switching to these vehicles.

Conclusion

This paper has shown the potential for AFs to lessen the impact of transportation on the environment. Difficult questions need to be answered on whether the benefits of having more environmentally friendly fuels outweigh the costs involved in making them available (including infrastructure as well as fuel costs). One line of argument would be to let the market decide on the basis of administered fuel prices, set to reflect the social cost of the fuels sold. However fuel prices are never likely to reflect their social costs. Fuel pricing is a complex issue, and any solution would inevitably be a ‘second best’ one.

Without initial assistance, the most promising ‘new’ fuel appears to be natural gas, with the potential, in the short-term, to win substantial niche markets (such as depot-based buses and heavy trucks) through fuel cost savings. Given some assistance, ethanol is a possibility as a fuel extender (perhaps as ‘diesohol’) or in niche markets, such as heavy trucks in certain areas, in the medium-term. Electric vehicles appear, in the absence of California-style zero-emission vehicle legislation, to require commercial availability of battery types with higher energy density and faster recharging than the lead/acid battery for market acceptance. Hydrogen fuel may be a long-term possibility, depending on the composition of Australia’s electricity generating facilities.

Widespread use of AFVs, which would probably only happen with Government encouragement, would be required for any of the AFs to have any significant impact on transport emissions. But without other policy actions, even with widespread introduction of these more environmentally-friendly fuels, emissions from transport seem likely to increase, given projected rates of fuel consumption (ABARE 1991), at least until (if ever) hydrogen from non-fossil sources becomes the major transport fuel or until electricity generation is based on renewable energy or both. It is a daunting task to attempt a conclusion about the way to go in regard to AFs. Not only is the technology not static, but there is the changing environment of regulated vehicle emission standards, the effect of these on fuel consumption, developments in fuel efficiency of gasoline vehicles, and the unknown impact of these on new vehicle costs.
References


Anker-Johnson, B & Schwobert, H (1990) Is Electricity or Methanol the Next Automotive Fuel? Environmental, Technological and Economic Considerations Melbourne: Paper presented to the 1990 Invitation Symposium of the Australian Academy of Technological Sciences and Engineering


Butcher, E W A (1990) Inter-state Commission Proposed National Road Pricing and Funding Scheme: A Review Canberra: AGPS


Clifford, M (1991) 'Gas Sparks Interest in Lean Burn Louisville', Truck Australia September.


Haley, J (1990) 'The Gas Option', The Open Road, December, pp 34-35.


ISC (1990) Road Use Charges and Vehicle Registration: a National Scheme Canberra: AGPS


Magazunik, D, Hamilton, R and Watson, H C (1990), Commissioned Study on Alternative Fuels: Methanol for Transport in Australia, National Energy Research, Development and Demonstration Program, Consultancy Study Report number 32

Metz (1991) Natural Gas in Transport: Potential for Natural Gas Within the NSW Transport System Sydney: NSW Department of Minerals and Energy


NSWDME (1990) Investigation into Ethanol and Alternative Transport Fuels in New South Wales, Sydney: Report to the Minister for Minerals and Energy


Rogers 1990) *Ethanol as a Transport Fuel*, paper presented at the Vehicles: Energy and Environmental Impact, seminar sponsored by the NSW Department of Minerals and Energy and AGL


Sperling, D and De Luchi, M (1991) *Alternative Transportation Fuels and Air Pollution Impacts* Paris: Consultants report to the OECD, Environment Directorate


Wilkenfeld, G (1991) *Greenhouse gas emissions from the Australian energy system, the impact of energy efficiency and substitution* Canberra: ERDC 22 Energy Research and Development Corporation