Bus technologies in Australia to 2020 and beyond

A discussion of the opportunity for new technology adoption for the Australian bus industry

Prepared for

VICTORIAN DEPARTMENT OF TRANSPORT

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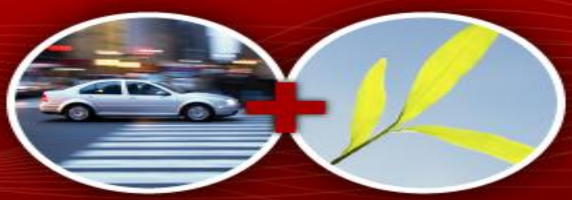


Contents

Appendices

List of figures

List of tables

Executive summary

The Victorian Department of Transport recently commissioned Rare Consulting to conduct a study of the degree to which alternative fuels offer a practical alternative to diesel fuel in the Victorian bus fleet. This paper is the second of six stages of work under that study, and constitutes an opportunity analysis covering the state of development and prospective future adoption of a range of alternative fuels, drivetrains and component systems in the Australian bus industry.

The key findings of this analysis will subsequently be used to provide the Department of Transport with advice on the near-term fuel and technology opportunities to reduce the Victorian bus fleet's exposure to the price and availability risks associated with wholesale dependence on conventional diesel fuel. However, opportunities associated with behaviour change were excluded from this assessment as they were considered outside the scope of the project brief.

Strategic context

Australia's national bus fleet predominantly runs on automotive diesel fuel, an increasing proportion of which is being derived from international sources. However, growing uncertainty concerning both the supply and price outlook for conventional oil-based fuels is causing many operators of commercial vehicles to examine alternatives as a way of hedging against increased fuel price volatility. Some of these alternatives also deliver co-benefits like better air quality and fewer greenhouse emissions.

Discussion about alternatives to conventionally powered road vehicles is not new. Alternatives to conventional internal combustion engines have been available in one form or another for more than a century. The same can be said for alternative fuels.

What has changed in recent years is a dramatic strengthening in the global case for investment in the development and commercialisation of alternative fuels and drivetrain technologies for road transport. This can be attributed to the combined influence of two global imperatives. The first relates to increasing uncertainty about the future availability and price outlook for conventional fuels. The second relates to concerns about the adverse environmental impact of conventional fuels on both air pollution and global warming. This study considers the result of those factors in driving the development of vehicle technologies and alternative fuels available to bus operators.

Bus industry operators have a degree of financial vulnerability in the face of increasing uncertainty in fuel prices and the future treatment of carbon emissions under some form of pricing scheme. This has led to the convergence of three strategic pressures shaping a new fleet management environment for operators. These pressures include maintenance of commercial margins, management of competition, and increased compliance and reporting burdens.

In response to this new paradigm, bus operators must consider fuel and technology options to reduce costs (fuel consumption) and to differentiate their service. However, one of the principal challenges associated with this strategy is the considerable uncertainty in the business case for investment in fuel efficiency/emissions improvements. This uncertainty commonly relates to three areas:

- the accuracy of the baseline measurements;
- the suitability (or otherwise) of specific improvements to the structure and nature of the business;
- the real-world costs and benefits of individual improvement actions.

The uncertainties surrounding predicted net outcomes create an investment uncertainty that often results in a level of risk that is not acceptable in a highly competitive, commercial environment. From an operator's perspective, there is an obvious commercial risk inherent in pursuing high capital cost options if the desired outcome of reduced fuel use is uncertain. This issue is considered one of the major explanations for why the transport sector in general has been accused of pursuing relatively minor improvements in fuel efficiency and emissions reduction.

Victorian bus fleet and emissions

In terms of vehicle numbers, the small size of Australia's bus fleet – 84,000 vehicles in total, of which Victoria accounts for just 18,000 (ABS 2009) – means that Australia is predominantly an adopter of technologies developed overseas, particularly in the areas of engine, drivetrain, emissions and safety.

The limitations of being a technology taker are compounded by a very old fleet (average bus age in Victoria is 11.4 years) with a slow rate of turnover. Combined, these factors result in a very slow penetration of new vehicle technology into the national fleet.

However, the average age varies with the particular application – many operators replace metropolitan and inter-regional buses after an 8–12 year service contract, and older buses are often moved to regional services or sold to operators in other states who use them at a lower intensity. This task flexibility suggests a need to achieve sufficient payback on any investment in fuel or drivetrain technology within the first service life, given that the re-tasking of a bus may also affect the fuel savings achieved in that new role.

In terms of carbon emissions, buses account for a relatively small proportion of total Victorian transport emissions, comprising less than 2% (BusVic 2009a) (Figure 1).

However, while total GHG emissions from buses are relatively small compared with emissions from cars and trucks, bus industry data indicates a significant growth in bus patronage of over 25% (to approximately 100 million passenger kilometres) in the three years to 2008–2009 (BusVic 2009b). The significance of this trend is that scheduled services have increased at roughly the same rate as patronage (BusVic 2009a), with the likely result that an increase in bus numbers is also causing emissions to increase correspondingly.

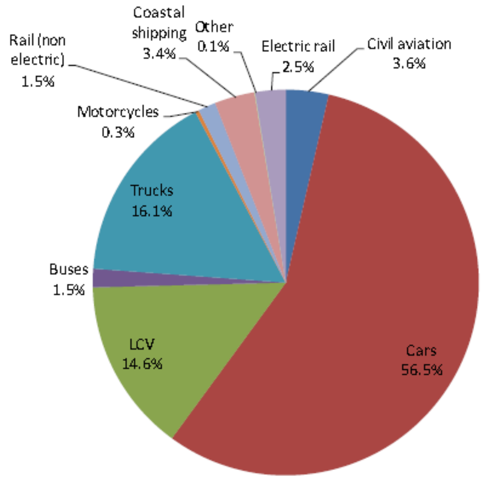


Figure 1

Victorian transport emissions 2007 (BusVic 2009a)

Opportunities for substitution or reduction in diesel use

Within the scope of this study, opportunities for reductions in diesel use were identified and assigned to one of three broad categories: alternative fuels, alternative drivetrains, and emerging vehicle technologies. The opportunities are shown in Table 1.

Table 1 Potential opportunities to reduce diesel use in the bus industry

Alternative fuels	Alternative drivetrains	Vehicle technologies
Biofuels	Fully electric	Improved vehicle aerodynamics
Natural gas	Hybrid electric	Ancillary equipment/accessories
Synthetic diesel	Mechanical hybrid	Transmissions
Liquefied petroleum gas		Improved tyre technology
Hydrogen		
Other: electric, solar, compressed air		

Each of the fuels and technologies were evaluated against four criteria to judge their potential for adoption into the bus industry. The four criteria are:

- fleet suitability
- estimated benefit (fuel and emissions)
- cost implications
- timeframe to realisation.

Outlook for alternative bus fuels

An analysis of the available information for each alternative fuel gives rise to the following specific observations regarding the opportunity to substitute significant commercial quantities of each fuel for diesel in the short to medium term (with *short term* defined as the next 8–10 years, and *medium term* as 10–15 years).

- There is an increasing body of authoritative literature which suggests that first generation biofuels (and biofuel blends) do not provide any substantial greenhouse emissions benefit relative to conventional transport fuels. In addition, the production of these fuels is likely to be limited by the combined constraints of land availability and food demands. These two factors, coupled with rising feedstock prices for producers and the foreshadowed imposition of a federal fuel excise on all alternative fuels from 1 July 2011 (in accordance with the *Fuel Tax Act 2006*), are likely to result in the reduced cost-competitiveness and reduced availability of this fuel in the future.
- Second and third generation biofuels are likely to figure prominently in the future transport energy mix in the long term. The commercial availability of these fuels will, however, depend upon substantial breakthroughs in production technology. As a consequence, these second generation fuels are not expected to be available in significant volumes before 2025.
- CNG is being increasingly used in urban bus fleets in Australia and a small number of light-duty rigid trucks (which often share the characteristic with many bus operations of operating ‘back to base’). There is significant uncertainty about the greenhouse benefit of some natural gas engines when considered on a life cycle basis (Garnaut 2008, COAG 2008). This uncertainty relates to the lower combustion efficiency of spark-ignited natural gas engines relative to compression ignition diesel engines (Orbital 2007) and the operating cycle of the vehicle.
- Interest in LNG fuel for long-haul and back-to-base truck operations has been growing, but adoption has been largely constrained by a lack of widespread availability of the fuel, lack of factory-supported engine options on new trucks, and the cost of engines that are available. The situation with respect to all three of these limitations is expected to improve considerably in the next 12–18 months. However, for most bus operations (except perhaps interstate and regional coaches) LNG fuel holds no advantage over CNG and is also more costly. An evaluation of net greenhouse benefit from LNG yields mixed results, due largely to variations in the combustion efficiency of different natural gas add-on technologies.
- Substantial research and development work has been undertaken in respect of the commercial production of synthetic diesel using CTL and GTL. When considered on a life cycle basis, the emissions generated by CTL and GTL fuels are significantly higher than conventional transport fuels, ranging from 50–90% higher (depending on energy source) based on the results of a life cycle analysis conducted by Rare. The future commercialisation of these transport fuels is likely to be constrained by the need to develop more carbon-efficient manufacturing processes and/or develop carbon capture and storage technologies. As a consequence, synthetic fuels are unlikely to be available for transport use in the short to medium term.

- LPG is already widely used in sections of the passenger car market, helped by federal government incentives for the purchase of LPG conversions. However, its use in the truck and bus segments has been limited (apart from niche applications relying on aftermarket bi-fuel systems that range from crude to relatively sophisticated). However, none of the major vehicle manufacturers is developing systems for application in the truck or bus segments. The outlook for this fuel in the bus sector is therefore considered of little significance.
- Hydrogen (and fuel cell vehicles) are still very much in the prototype stage and the advancement of this technology for transport is complicated by major challenges relating to the cost, complexity, fuel handling and absence of low carbon production sources. The majority consensus within the transport industry, including that of the authors, is that hydrogen will not be available as a transport fuel in the next 25–30 years, if at all.

Outlook for alternative drivetrain and vehicle technologies

Applying the same four criteria used in the alternative fuels assessment gives rise to the following specific observations about the future opportunity for drivetrain and vehicle technologies for the bus fleet.

- The greatest technology opportunity for reducing diesel fuel use in buses lies in the adoption of hybrid electric drivetrains (short term) and fully electric drivetrains (medium term). These two technologies can achieve fuel and emissions reductions of up to 60% for hybrids that are well matched to the real-world duty cycle of the vehicle, and up to 80% for electric buses if the electricity is sourced from renewable sources.
- Hybrid drivetrains constitute the most significant near-term opportunity for the bus segment, given the current and emerging availability of models with this drivetrain. However, care needs to be taken in specifying the hybrid system to accurately match the duty cycle requirements of the bus if fuel and emissions savings at the upper end of the spectrum hope to be achieved.
- Mechanical hybrids and other drivetrain or gearbox technologies are not expected to present a viable opportunity for buses in the near term, owing largely to the lack of products being developed for buses in this area.
- Low rolling resistance tyres present a current, cost-effective and reliable pathway for small reductions in both fuel use and emissions. Products are available in a range of sizes and the perceived disadvantages have been addressed by manufacturers over time.
- The opportunity to reduce fuel consumption and emissions from the use of electrically powered ancillaries is limited in the near term. As hybrids and electric buses are further developed, these ancillaries are expected to enhance and enable the benefits of those drivetrains.

Likely near-term opportunities for the bus industry

None of the fuel alternatives or vehicle technologies assessed in this study constitutes an opportunity for wholesale replacement of diesel across all sectors of the diesel bus fleet. Rather, the study team believes that the more likely pathway will involve the simultaneous advancement of a number of opportunities, with each one suited to specific sub-segments within the total bus fleet. Table 2 shows the estimated timing of wide-scale adoption of alternative fuels and drivetrains in each of three bus segments.

Combining the insights shown in Table 2 produces a shortlist of three opportunities likely to offer short-term benefits in reducing diesel sensitivity in the national bus fleet: natural gas fuel (as CNG or LNG), hybrid electric drivetrains, and low rolling resistance tyres. Of these, low rolling resistance tyres is the only opportunity currently available with a significant market history, to the extent that it is no longer considered an emerging or potential opportunity.

Electric buses represent an additional opportunity in the medium to long term; however, this opportunity will be limited to specific urban applications unless a major technological breakthrough in battery technology can be achieved. Furthermore, the greenhouse benefits achievable with this technology will only be fully recognised when the electricity used to charge these vehicles can be sourced from renewable sources, or when the carbon generated in electricity generation can be captured and stored. Neither of these developments is likely in the near future.

The main implementation considerations for each opportunity are summarised below.

NATURAL GAS FUELS (CNG AND LNG)

The technical and economic viability of natural gas, at least in CNG form, has been demonstrated in many bus applications around the country. CNG has been primarily used in back-to-base urban buses or those with relatively short-range requirements. Theoretically, LNG could be used where a longer operating range is required.

A degree of uncertainty remains with respect to the life cycle emissions of gas due to the fact that the actual emissions reduction varies between compression-ignition and spark-ignited systems, between different types of compression-ignitions systems, and even in different installations of the same system due to duty cycle variations.

Complicating the issue further, aftermarket installations of bi-fuel systems using CNG or LNG have no current agreed protocol by which to compare emissions performance with new gas or diesel engines. Rather, there appears to be an opportunity to resolve this uncertainty by establishing state-based tailpipe methane limits for aftermarket vehicle conversions. Ideally, such an agenda would be undertaken in partnership with other states to encourage uniformity in regulations on a national basis.

Table 2 Estimated suitability and timeframe to realisation for alternative fuels and technologies in segments of the bus fleet

Fuel	2010			2015			2020			2025			2030		
	Metro	Region	Charter	Metro	Region	Charter	Metro	Region	Charter	Metro	Region	Charter	Metro	Region	Charter
Biofuels	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓
LPG	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
CNG	✓	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
LNG	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✓
Synthetic diesel	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓
Hydrogen & fuel cells	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
Solar & compressed air	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Electric hybrids	✓	✗	✗	✓	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓
Mechanical hybrids	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗
Electric vehicles	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✓

HYBRID ELECTRIC DRIVETRAINS

There are two principal barriers to the increased adoption of hybrid drivetrain technologies in the Victorian and Australian bus fleets. The first challenge relates to the additional capital cost of these vehicles relative to equivalent conventional vehicles. The second barrier relates to the current limited availability of hybrid vehicles within the rigid truck and bus segment.

A few hybrid buses have undergone trials in the eastern states of Australia, with mixed results. Lessons to date suggest that both the bus supplier and the operator need an intimate understanding of the real-world duty cycle in which the bus will operate, and that this understanding should drive the specification or choice of hybrid for that application. In essence, the only pathway to achieving the maximum potential benefits of the system is to carefully match the strengths and weaknesses of the technology to the demands of the application.

FULLY ELECTRIC DRIVETRAINS

The analysis completed for this study gives rise to two major observations with respect to the likely availability of electric drivetrains in the near future. The first is that significant development is occurring in electric drivetrain technology for buses, but that this technology will, for some time into the future, be suitable only in narrow or niche urban applications. Depending on the energy storage system employed, it may require the development of significant infrastructure for charging.

The second observation is that the environmental performance of these vehicles is almost entirely dependent upon the sourcing of electricity generated by renewable resources.

The development of electric buses and charging infrastructure for Australia, and Victoria in particular, is therefore likely to be dependent upon the resolution of the following specific issues:

- development of a protocol (or standards) for electric vehicle batteries
- acceleration in the development of renewable electricity supplies in Victoria
- development of standards and regulations for electric vehicle charge points.

1 Introduction

The Victorian Department of Transport recently commissioned Rare Consulting to conduct a study of the degree to which alternative fuels offer a practical alternative to diesel fuel in the Victorian bus fleet.

This paper is the second of six interrelated stages of work in the overall study, which are:

- Stage 1 – Construction of a business as usual baseline
- Stage 2 – Opportunity analysis
- Stage 3 – Validation of opportunity analysis findings
- Stage 4 – Scenario construction and analysis
- Stage 5 – Validation of draft study findings
- Stage 6 – Final synthesis and final report.

This opportunity analysis examines the state of development, and the prospects for future adoption of a range of alternative fuels and drivetrains that could reduce dependence on diesel fuel. It also separately considers in broad terms some component systems and equipment that can reduce diesel fuel consumption on existing vehicles.

There may be some divergence between the findings of this and other reports that evaluate the potential adoption of alternative fuels in Australia, including some of those cited in the brief for this project. A number of those studies are constrained in respect of their consideration of fleet architecture and subsequently advance findings and recommendations that are of varying relevance to specific vehicle types and vehicle applications. Whereas some analysts assume market-wide adoption rates for technologies or fuels across broad vehicle categories (e.g. ‘heavy vehicles’, or broad rigid/articulated split), Rare cautions that many new technologies can deliver their claimed benefits only when applied under very specific operating conditions, dependent largely on the vehicle duty cycle. As the market understands these limitations, the actual adoption rates will vary significantly from those predicted by a high-level assessment of the potential opportunity.

Consequently, any analysis of the likely potential adoption of alternative fuels and technologies requires a segment-by-segment consideration of the suitability of that technology. While Rare has found this analysis to be overlooked in many published studies, this ‘level of fit’ analysis of specific technologies is the basis of the assessment provided for the bus industry in this report.

In addition to an examination of the potential bus fleet application, each of the alternative fuels is considered in the context of two additional criteria: likely timing to widespread adoption, and the key challenges faced in adopting the fuel (Section 4).

For each of the technologies considered (Section 5), the four criteria are similar to those for fuels:

- potential fleet application
- estimated benefit (fuel and emissions)
- estimated costs
- timeframe to realisation.

The key findings of this analysis will subsequently be used to provide the Department of Transport with advice on the near-term opportunities to reduce the Victorian bus fleet's exposure to the price and availability risks associated with wholesale dependence on conventional diesel fuel.

For the purposes of this study, only those technologies that relate specifically to alternative fuels and vehicle drivetrains have been considered. Opportunities associated with behaviour change (driver and corporate practices) can be appealing to some operators for their low implementation costs, and indeed simply ensuring vehicles are functioning as intended through regular inspection and maintenance can bring worthy fuel savings. However, these and other non-vehicle specific technologies like telematics and information systems which are more appropriately considered under the banner of infrastructure improvements, have not been considered as part of this assessment as they were not considered within the scope of fuel and drivetrain opportunities discussed in the original brief.

2 Strategic context

Australia's national bus fleet predominantly runs on automotive diesel fuel, an increasing proportion of which is being derived from international sources. However, growing uncertainty concerning both the supply and price outlook for conventional oil-based fuels is causing many operators of commercial vehicles to examine alternatives as a way of hedging against increased fuel price volatility. Some of these alternatives also deliver co-benefits like better air quality and fewer greenhouse emissions.

Notwithstanding, discussion about the development and adoption of alternatives to conventionally powered road vehicles is not new. Alternatives to conventional internal combustion engines have been available in one form or another for more than a century. The same can be said for alternative fuels – the technology to develop synthetic diesel fuels has been in existence for more than sixty years, having first been developed during World War II.

What has changed in recent years is a dramatic strengthening in the global case for investment in the development and commercialisation of alternative fuels and drivetrain technologies for road transport. This strengthening can be attributed to the combined influence of two global imperatives. The first imperative relates to increasing uncertainty about the future availability and price outlook for conventional fuels. The second relates to the adverse environmental impact of conventional fuels on urban air pollution and global warming.

An overview of both of these imperatives was presented in the introductory discussion of Rare's proposal to conduct this study. The current discussion concerns the relevance of these factors, and the resulting framework of incentives/disincentives being considered and planned by various levels of government as a response to these factors, and their effect in shaping the operating landscape for Australia's bus operators.

2.1 Bus market considerations

The size of the Australian national bus fleet is about 84,000 vehicles (ABS 2009), which represents an increase of 18% since 2004. Of these, Victoria accounts for 18,000 with a slightly lower overall growth rate (15%) over the same period.

This relatively small market for new buses (in global terms) means that the Australian market is predominantly a technology taker – adopting innovations from overseas manufacturers, particularly when it comes to engine and drivetrain technologies, emissions reduction equipment, and safety features. This is reflected in the timing and stringency of mandatory design standards in these areas, which typically lag behind European compliance requirements by one to three years (although the lag time is progressively shrinking).

The limitations of being a technology taker are compounded by a very old national fleet (by international standards) with a slow rate of turnover. The average age of buses nationally is 11.0 years (11.4 in Victoria) and getting older (ABS 2009). Meanwhile the overall attrition rate (de-registrations) is less than 4% (ABS 2008). These factors result in a very slow penetration of new vehicle technology into the national fleet.

Like the road freight sector, bus industry operators have a degree of financial vulnerability in the face of increasing uncertainty in the price outlook for conventional diesel fuel and the future treatment of carbon emissions under some form of pricing scheme (e.g. CPRS). Unlike the freight industry, a major proportion of the freight (passenger) task in the bus sector is dominated by major players servicing government contracts in the major cities.

Despite their differences, both segments of the transport industry are facing new challenges imposed by the energy and environmental imperatives introduced earlier, leading to a new fleet management paradigm.

2.2 A new fleet management paradigm

Commercial vehicle operators have always faced pressures associated with conducting business in a competitive environment. However, the greenhouse agenda has precipitated the convergence of three strategic pressures that have shaped a new commercial fleet management environment. These pressures include maintenance of commercial margins, management of competition, and increased compliance and reporting burdens (Figure 2.1).

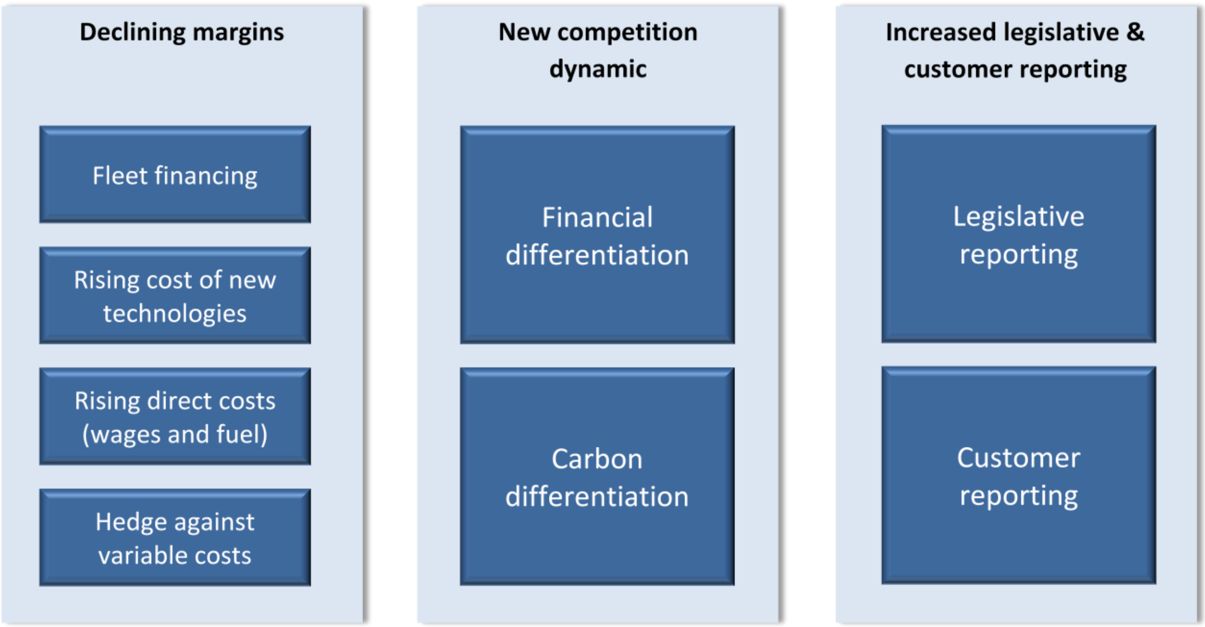


Figure 2.1

The evolving commercial paradigm for road freight operators in Australia

The direct financial pressure in the new paradigm relates to a continuation of declining profitability and typically low gross margins. Growing challenges associated with the sourcing of affordable capital for fleet expansion, coupled with increases in the capital cost of new vehicles required to meet ever tightening emission standards, suggests that fleet operators are likely to experience further reductions in what are already very lean financial returns. At the same time, direct costs for wages and fuel are rising, and operators are forced to establish complex arrangements to hedge against rising variable costs.

The second pressure relates to the changing face of competition as operators are being required to compete in a new market environment. As with many industries, transport has traditionally differentiated service offerings mainly on the basis of price with the exception of those operators servicing niche segments.

However, growing community interest in climate change has resulted in the addition of a new dimension to the competition dynamic in the transport industry, that is, carbon differentiation. An increasing number of bus customers (both private and government) are asking for information about the carbon intensity of transport services and individual companies' environmental credentials. This is creating pressure for operators to both understand their carbon liability and to introduce improvements that will contribute to an overall reduction in emissions. As a consequence, freight operators must now look to differentiate their service offerings on the basis of both cost and GHG emissions.

The final strategic pressure relates to the increased compliance and reporting burden that is falling on transport operators. These requirements are driven both by the introduction of new legislation (particularly the recent National Greenhouse and Energy Reporting Scheme and the Energy Efficiency Opportunities legislation) and the increased requirements of government customers who, in turn, are seeking to manage their own reporting obligations.

It is worth noting that the commercial impacts of these increased reporting and compliance requirements on individual operators are variable, given the diverse nature of the operators in the Australian bus industry.

2.3 Uncertainty – a major barrier to investment in energy efficiency

Fuel efficiency improvements are rarely evaluated on an isolated (or elemental) basis by Australian transport operators. More often, an opportunity is evaluated on the basis of its total net value to a given industry operator relative to incumbent technologies and practices before any implementation consideration.

Adoption of energy efficiency improvements by a bus operator is best modelled as a four-stage process (Figure 2.2):

1. Aggregation of data to develop an accurate emissions/energy baseline against which future improvements can be compared. With the exception of some of the larger fleets (and the very small ones) the emissions assessment is typically performed by an external specialist who is contracted by the operator.

2 Comparison of current practices with industry best practices in order to derive a sound estimate of the potential improvements (if any) that could be realised based on an analysis of potential improvement actions.

3 In the event that an improvement opportunity (or bundle of opportunities) is identified, the business must then develop an improvement strategy, generally requiring preparation of a business case for investment consideration.

4 Implementation of the improvements, measurement of actual net benefit (relative to net estimated benefit) and reporting of outcomes to management. It is at this stage that the organisation is in a position to validate (or discredit) the business case that was used as the basis for investment in the improvement opportunity. Projects that deliver net negative returns generally serve to build internal resistance to the future adoption of additional improvement actions and, should a pattern of these outcomes emerge, the corporate willingness to advance energy efficiency reductions diminishes.

One of the principal challenges with the adoption of this four-stage process relates to the considerable uncertainty surrounding the derivation of the business case for investment in fuel efficiency/emissions reduction improvements. In the vast majority of cases, the improvement process is characterised by a high level of uncertainty surrounding:

- the accuracy of the baseline measurements;
- the suitability (or otherwise) of specific improvements to the structure and nature of the business;
- the real-world costs and benefits of individual improvement actions.

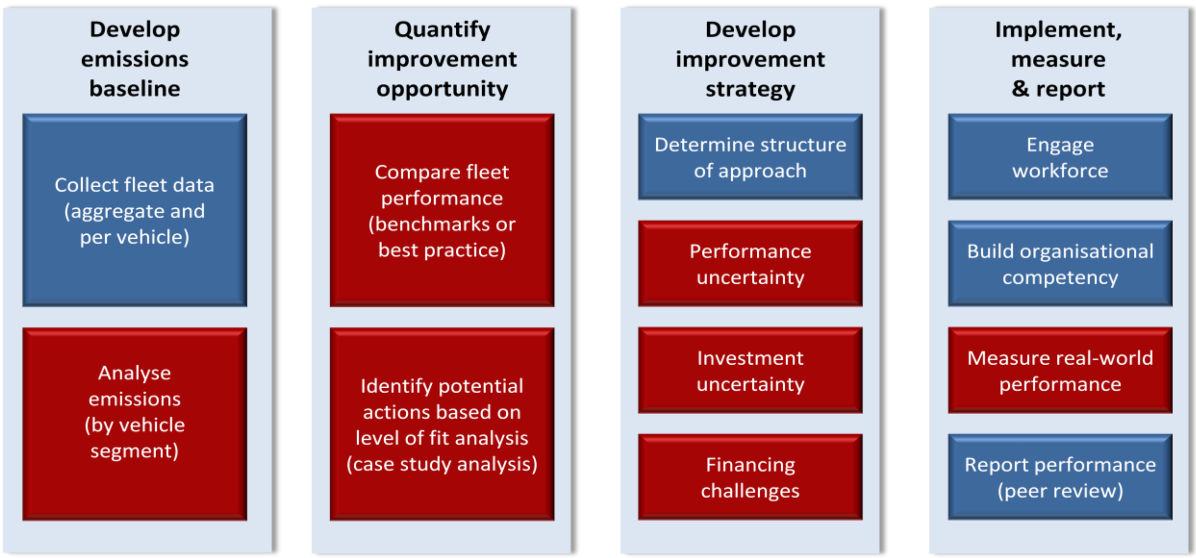


Figure 2.2

Key elements of a typical fleet improvement program for a transport operator (with key areas of uncertainty shaded in red)

Uncertainty in these preliminary stages is a key issue. Unresolved, it will lead to uncertainty in relation to the likely quantum of both the performance improvement (fuel efficiency or emissions benefit) and the financial outcomes. Obviously these issues make the preparation of a convincing business case particularly challenging.

Most importantly, however, the uncertainties surrounding predicted net outcomes create an investment uncertainty that often results in a level of risk that is not acceptable in a highly competitive, commercial environment (Figure 2.3). From an operator's perspective, there is an obvious commercial risk inherent in pursuing high capital cost options if the desired outcome of reduced fuel use is uncertain. This issue is considered to provide one of the major explanations for why the transport sector in general has been accused of pursuing relatively minor improvements in fuel efficiency and emissions reduction, given that more substantial improvements require large levels of investment that are too risky.

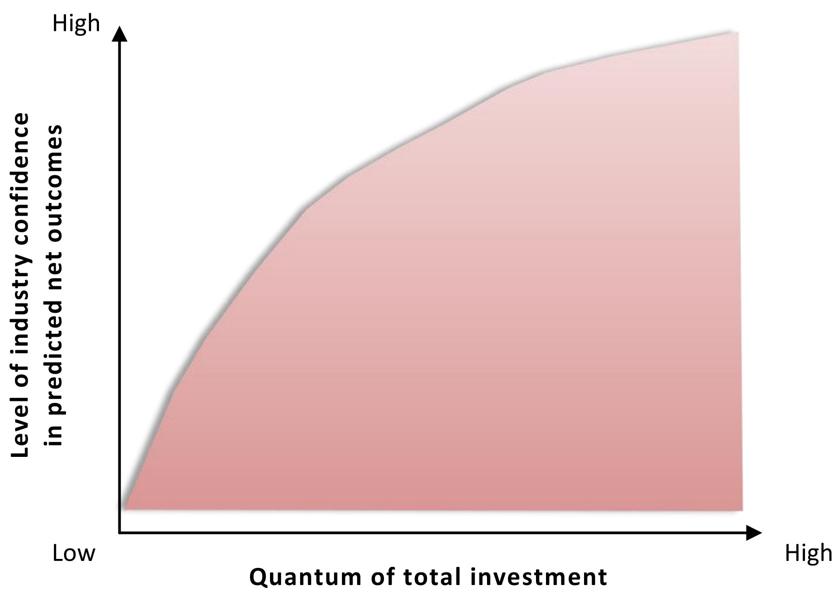


Figure 2.3

High levels of investment uncertainty are a major barrier to the introduction of energy efficiency innovations in highly competitive industries such as the land freight industry

3 Nature of the Victorian bus fleet and emissions

3.1 Victorian bus fleet population and age profile

The Victorian bus fleet can be divided into five discrete bus fleet segments based on common vehicle types and route characteristics:

- metropolitan services
- regional inter-town services
- regional intra-town services
- coaches (linehaul)
- school and charter bus services.

Based on passenger numbers, scheduled route and school services represent the most significant proportion of the total fleet with approximately 140 million passengers carried compared to 17.4 million charter bus passengers (BusVic 2009b). Information provided by the Victorian Department of Transport (DoT 2010) indicates that the metropolitan bus fleet represents a significant proportion of the total route service bus fleet, servicing 87% of passenger trips in Victoria with a fleet of over 1500 buses in 2008–2009.

The remaining bus fleet is characterised by a large number of smaller bus and coach operators that service regional areas. Regional buses carry over 13 million passengers annually while regional coaches account for approximately 1 million passengers.

Overall the bus fleet in Victoria has an average age of just over 11 years (ABS 2009). However, the average age varies with the particular application – many operators replace metropolitan and inter-regional buses after an 8–12 year service contract, and older buses are often moved to regional services or sold to operators in other states who use them at a lower intensity.

The flexibility required in reassigning buses interstate or to regional areas in later life is an important consideration when identifying the relevant engine technologies that can be adopted to improve fuel efficiency. The ability to achieve sufficient payback on the investment in alternative technology and fuel systems within the first service life may be essential if the transfer of a bus to other operations in later life also changes the fuel savings achieved when operated in the new duty cycle.

3.2 Greenhouse emissions

More than 90% of Victoria's transport-derived carbon emissions are attributed to road transport. Passenger vehicles (both commercial and private) account for the largest share of these emissions, as illustrated in Figure 3.1. In comparison, emissions from buses account for a relatively small proportion, comprising less than 2% (BusVic 2009a).

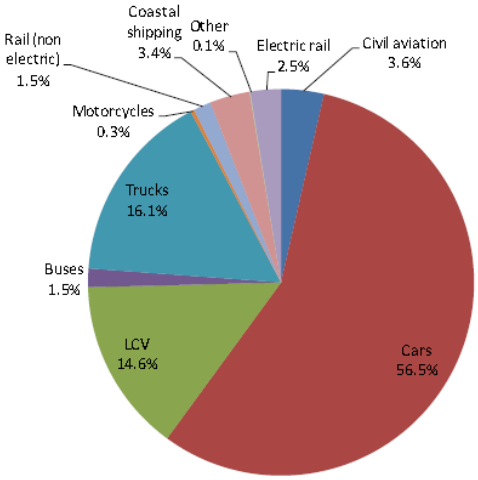


Figure 3.1

Victorian transport emissions 2007 (BusVic 2009a)

Although total GHG emissions from buses are relatively small compared with emissions from cars and trucks, bus industry data indicates a significant growth in bus patronage of over 25% (to approximately 100 million passenger kilometres) in the three years to 2008–2009 (BusVic 2009b). The significance of this trend is that scheduled services have increased at roughly the same rate as patronage (BusVic 2009a), with the likely result that an increase in bus numbers is also causing emissions to increase correspondingly. The trend of increased bus patronage is mirrored in overall public transport growth as illustrated in Figure 3.2, where it can be seen that passenger kilometres associated with public transport exceeded private vehicle transport in Melbourne during 2007 and 2008, for the first time since at least 1990.

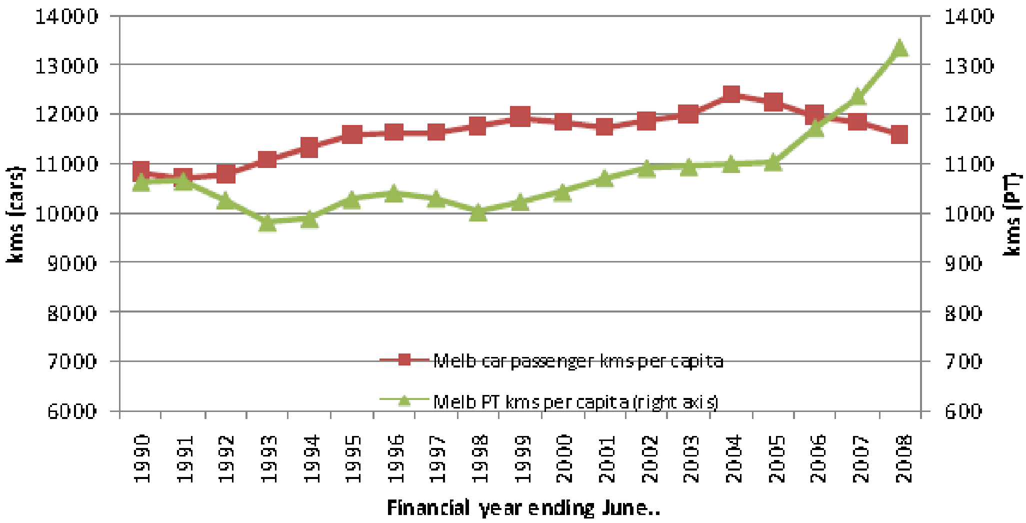


Figure 3.2

Melbourne car and public transport passenger kilometres per capita 2007 (BusVic 2009a)

4 The outlook for alternative fuels

4.1 Biofuels (ethanol and biodiesel blends)

There is a significant body of literature which suggests biofuels deliver improved environmental and economic outcomes relative to conventional transport fuels (e.g. CSIRO et al. 2003). Much of this research was developed at a time when little was known about the real-world performance of biofuels, with researchers relying on desktop assessments conducted by the biofuels industry (e.g. CSIRO 2001).

In more recent times, an increasing body of international research has questioned the net environmental benefits of biofuels when considered on a life cycle basis (OECD 2007, UNEP 2009). In particular, there is significant concern about the carbon, wider environmental and social impacts of first generation biofuels (i.e. those derived from agricultural feedstocks and palm plantations). A growing body of evidence suggests that previous biofuel life cycle analysis assessments have not taken into account the adverse carbon impacts associated with land clearing and production methods.

There are also significant questions concerning the economic performance of first generation biofuels in Australia. Dramatic escalation in the price of biodiesel feedstocks and high costs of small-scale production plants have resulted in these fuels being only marginally cheaper than conventional diesel fuels.

In the 2010–2011 federal Budget, the government announced it would introduce an energy-based fuel excise system. This change will involve setting the excise on fuel ethanol under the *Fuel Tax Act 2006* at 25 cents per litre from 1 July 2011, reducing to 12.5 cents per litre by 1 July 2015. Additionally, the government will provide an offsetting grant to ethanol producers of 22 cents per litre from 1 July 2011 reducing to zero on 1 July 2015.

On the other hand, the Budget did not announce any changes to the fuel tax approach applied to biodiesel. Given the uncertainty in how the Australian Tax Office will treat biodiesel for excise purposes, and considering that biofuels are only marginally cheaper than conventional fuels without being subject to federal fuel excise, the imposition of a fuel tax for biodiesel from 1 July 2011 is likely to make the use of this fuel uneconomic.

Past field trials of high-blend first generation biofuels (i.e. 100% or 80% biodiesel) have also raised significant questions about the suitability of current biodiesel products for heavy vehicle operation. Australian trials of biodiesel (Camden City Council 2005) revealed significant issues associated with variable fuel quality, with adverse consequences for engine and operating performance of heavy duty vehicles.

Manufacturer concern about the observed variability in the quality (specifically the gel point) of biodiesel has resulted in commercial vehicle manufacturers setting somewhat conservative limits (i.e. 5%) on the use of biodiesel in their vehicles.

4.1.1 Potential fleet application

Relative to most other alternative fuels, biofuels possess an inherent advantage in that they can be blended with conventional fuels (albeit at low volume blends) and used in conventional internal combustion engines without requiring modification to the vehicle.

In heavy vehicle and bus applications, conventional diesel can be blended with ethanol or biodiesel. The percentage of biofuel blends for road use is generally limited to 10% or less in Australia. While E10 ethanol-petrol blends are typically promoted as an alternative to conventional unleaded petrol for light vehicles, B5 biodiesel is promoted as an alternative to conventional diesel for heavy vehicles.

Internationally, there are over 50 countries with biofuel mandates (McKinsey 2009). High blends of biofuels are used in countries such as Brazil, where 20–25% blends are mandated, but this change has required Brazilian automakers to adapt their gasoline engines to run smoothly with these higher blends. Biofuel blends of 85% are available in some parts of the United States, South America and Europe but can be used only in ‘flexible-fuel vehicles’ where the internal combustion engines have been modified to accept higher concentrations of ethanol.

4.1.2 Key challenges

As mentioned earlier, few of the first generation biofuels deliver any significant greenhouse benefit when considered on a full fuel cycle basis. While there is a body of literature (CSIRO 2008, King 2007, TNO et al. 2006) that suggests biofuels can deliver a greenhouse reduction in the order of 50%, these analyses generally ignore on-farm emissions of nitrogen fertilizers and land management practices. When these effects are taken into account, many recent studies suggest that the majority of first generation biofuels derived from agricultural feedstocks deliver, at best, only marginal greenhouse benefits or, at worst, dramatic increases in greenhouse emissions. (UNEP 2009, GAO 2009).

Other challenges associated with first generation biofuels include competition between use of feedstocks for fuel or food, land use constraints and management practices, and greater recognition of other negative environmental impacts such as land and waterway degradation (UNEP 2009). As such, first generation biofuels are unlikely to constitute a significant proportion of the global fuel mix apart from increasing uncertainty regarding their greenhouse benefits and overall sustainability.

Second and third generation biofuels, such as cellulosic ethanol and biodiesel (derived from woody biomass) and algal biodiesel, bio-propanol and bio-butanol have been assessed as holding significant potential as transport fuels in the future (CSIRO 2008, Jamison Group 2008, IEA 2008). However, the potential contribution of these sources is currently constrained by the experimental nature of second and third generation technologies and will require supportive policy and market environments to achieve large-scale commercialisation (IEA 2008).

In any event, under the best case scenario in which the technological barriers associated with second and third generation biofuels are overcome, they are only likely to be able to meet about 25% of global fuel demand in 2050 (UNEP 2009).

4.1.3 Likely timing

First generation biofuels are available in Australia now, but supply is limited and sufficient only to support low blends with conventional petrol and diesel (COAG 2008, Jamison Group 2008). Additionally, many domestic biodiesel production facilities closed during 2008 due to limited availability of low cost feedstocks (ABARE 2010).

As a result, Australia currently has approximately 330 ML ethanol production capacity and 265 ML biodiesel production capacity (ABARE 2010). As demand for biofuels is significantly higher than Australia's production capacity (835 ML of ethanol and 77 ML of biodiesel were consumed in 2007–2008) the supply is supplemented by imports (ATF 2010).

While some studies suggest that second and third generation biofuels are likely to be available in the medium term (CSIRO 2008, Jamison Group 2008), the general consensus appears to be that these fuels are unlikely to be available in significant quantities before 2020 and 2030 respectively (UNEP 2009, IEA 2008, McKinsey 2009, King 2007).

4.2 Natural gas

4.2.1 Potential fleet application

Owing to the low energy density at normal conditions, natural gas is typically used in transport in either compressed form as compressed natural gas (CNG) or in liquefied form as liquefied natural gas (LNG). CNG is typically stored in high pressure vehicle tanks (between 2800 and 3200 psi) while LNG is stored in cryogenic tanks (–160 ºC) at relatively low pressure.

Relative to low-sulphur diesel fuel, natural gas can deliver a carbon benefit in the order of 10% (CNG) to 15% (LNG) when considered on a full fuel cycle basis. Some studies (CSIRO 2001) suggest that the benefit could be as high as 25%, but this assessment is dependent upon the source of the natural gas and the nature of the electrical energy used to compress or liquefy the gas.

As at January 2010, there were more than 1500 government buses (CNG only) and 150 heavy vehicles (CNG and LNG) operating on natural gas across Australia, with more on order. The majority of gas fuelled buses and small trucks use spark-ignited engine technology and operate on full (100%) gas. The majority of heavy trucks operating on natural gas are using a dual-fuel technology developed for installation on the Caterpillar C-12 and C-15 engines (LNG only). These trucks are operating in mid-sized fleets in Victoria and Perth, where reasonable supplies of LNG are available, but the dual-fuel technology used by these vehicles is suited only to mid-life engine rebuilds since the engine and fuelling combination does not meet more stringent emission standards for heavy vehicles adopted in January 2008 (i.e. ADR 80/02). Even more stringent emissions compliance limits (ADR 80/03) were subsequently adopted in January 2010.

Another gas engine technology – Westport Innvoations high pressure direct injection – was developed jointly under the Australian Government's Alternative Fuels Conversion Program (AFCP). This technology has shown the potential for producing significant fuel savings and greenhouse reductions, and it has become the only OEM-supported gas engine in the upper heavy duty market since becoming available as a factory fitment on three Kenworth models.

However, its penetration into the market has been constrained considerably by a high conversion cost, to the extent that it is only economically viable in high mileage linehaul applications. The engine size and power rating of this engine makes it mostly unsuitable for bus applications.

The use of CNG and LNG has been subject to a greater level of scrutiny than any of the other alternative fuels, owing to the operation of the AFCP between 2000 and 2008. Under the auspices of this program, a number of heavy vehicle operators conducted trials of natural gas operation that were subject to independent assessment and documentation of real-world economic and environmental benefits. Examination of the findings of these case studies reveals:

- variable greenhouse outcomes
- variable operating performance with improved outcomes for later trials
- strong financial and economic outcomes, due largely to the low price of LNG relative to diesel.

The above discussion gives rise to a question concerning the apparent slow rate of adoption of gas as a mainstream transport fuel, particularly as LNG. The explanation for this anomaly lies in the fact that the availability of CNG refuelling and LNG production infrastructure has in the past been severely constrained, particularly on the East Coast. It is expected that this barrier will soon be overcome with BOC's plans to build an integrated refuelling network servicing the main north–south corridor from Melbourne to Brisbane, and other suppliers signalling similar intent. The first statewide network is already operating in Tasmania.

4.2.2 Key challenges

Despite the relative abundance of natural gas in Australia, its development as a mainstream transport fuel is constrained by a number of key challenges, including:

- a lack of natural gas refuelling infrastructure for general transport use in Australia and the high capital cost required to build such infrastructure (COAG 2008);
- significant uncertainty about the long-term price outlook for natural gas in the face of likely increased global demand for natural gas as an energy source (CSIRO 2008);
- severe limitations in the availability of manufacturer-supported natural gas vehicles in the Australian marketplace and the need for further advancements in the performance and durability of existing technologies (COAG 2008, Jamison Group 2008);
- newer diesel engines with exhaust treatment systems are narrowing the gap to natural gas engines in terms of cleanliness of exhaust emissions – removing one of the primary motivations for switching to gas (from a government perspective, at least);

- uncertainty about the 'well to wheel' benefits of using natural gas in lieu of petrol and diesel (Garnaut 2008, COAG 2008). Experience from the AFCP suggests that the utilisation of natural gas does not guarantee a better greenhouse outcome, with many of the vehicles tested under the program showing no advantage over an equivalent diesel engine, and some showing a significant disadvantage (COAG 2008).

4.2.3 Likely timing

CNG buses are already operating in Perth, Adelaide, Sydney, Canberra and Brisbane. Use of natural gas as a transport fuel is likely to continue, but will be limited to vehicles operating on a back-to-base basis in the short to medium term. While there has been progress in planning for LNG networks as described above, a similar situation does not appear to be occurring with CNG.

The lack of engine options in the heavy vehicle market in general – a major constraint in the past – also appears to be receding, with all the major truck manufacturers developing or investigating gas-compatible equipment. Several of these could be ready with new products as early as 2012.

4.3 Synthetic diesel

Synthetic diesel fuel is derived from natural gas or coal using the Fischer-Tropsch process. It is commonly referred to as gas to liquids (GTL) and coal to liquids (CTL). It is often promoted as an alternative to conventional diesel fuel for Australian transport, given Australia's abundant indigenous reserves of natural gas and coal.

The high energy intensity of current production technologies suggest that significant advances in production technology are needed to reduce the emissions intensity of production if this fuel is to be a serious option for transport in Australia (Australian Senate 2007).

In addition, there is considerable doubt about the capacity of this fuel to even match the greenhouse performance of conventional low-sulphur diesel fuel (CSIRO 2001, AutoCRC 2009).

4.3.1 Potential fleet application

The combustion properties of synthetic diesel are similar to those of conventional diesel. Consequently, synthetic diesel is wholly interchangeable with mineral diesel for transport operation, with significant opportunity to use this fuel in the existing diesel-powered vehicle fleet (i.e. passenger, light commercial vehicle, bus and heavy vehicles).

4.3.2 Key challenges

There are two principal challenges associated with the development of synthetic diesel in Australia. The first challenge relates to the non-existence of commercial production infrastructure and substantial challenges in developing this infrastructure given the high energy demands of current production technologies.

The second challenge relates to the higher life cycle emissions of synthetic fuels relative to conventional transport fuels. The magnitude of this emission penalty suggests that synthetic fuel production (particularly CTL production) will be viable only if it is combined with carbon capture and

storage, or uses renewably generated electricity to power the processing plant (Jamison Group 2008, Garnaut 2008).

4.3.3 Likely timing

There is a lack of consensus over the likely market availability in the future. Views on market availability range from as early as 2016 subject to necessary low carbon production technological breakthroughs (Jamison Group 2008), to other assessments which suggest synthetic diesel will only emerge as commercially viable after 2020 (CSIRO 2008).

Our views are largely in line with those of Professor Garnaut – that synthetic fuels will never be competitive under a carbon constrained economy owing to the high emissions associated with the production process which will incur a significant cost penalty following introduction of a carbon price (Garnaut 2008).

4.4 Liquefied petroleum gas

Liquefied petroleum gas (LPG) is a fuel consisting of a mixture of hydrocarbons – predominantly propane and butane. Under light compression, the gaseous mixture forms a liquid and is transportable in pressurised canisters within vehicles.

When considered on an equivalent energy basis, LPG has a carbon content that is 13% lower than that of low-sulphur diesel (CSIRO 2001). The realisation of this carbon benefit, however, relies upon the overall efficiency of the combustion process. At best, internal combustion LPG engines can only deliver greenhouse benefits in the order of 5–10% compared with conventional diesel. (Any claims of higher benefits are either factually incorrect or demonstrate that the evaluation of the technology may have been influenced by the leaning out of the diesel engine prior to the post-installation evaluation.)

There are a number of ‘cottage providers’ of LPG bi-fuel systems for heavy vehicles that use either gas fumigation or vapour injection technologies. Relative to modern compression ignition diesel systems, the cheaper gas fumigation process is relatively inefficient as a combustion process and therefore does not deliver significant greenhouse savings. Vapour injection systems offer better environmental outcomes but are limited by the sophistication of the integration between the gas central processing unit (CPU) and the diesel CPU. (A high quality handshake occurs when the gas CPU and the diesel CPU operate with little or no lag, resulting in a high level of dual-fuel efficiency. Cheaper systems typically provide an increased lag effect resulting in poorer combustion outcomes.)

Importantly, these technologies are not supported by the original equipment manufacturer engine provider, and purchasers of these systems must rely solely upon the limited support systems of the after-market technology providers.

Accurate assessment of the economic and environmental performance of these fuels is made difficult by the lack of case study data, but discussion with heavy vehicle operators (i.e. Linfox, Murray Goulburn and Boral Transport) suggests that the majority of these aftermarket systems are largely torque-toppers – that is, they provide additional power at the top of the torque curve but do not result in any noticeable reduction in operating costs. However, recent developments by some of these

companies are producing quite sophisticated systems which can achieve higher gas substitution rates – improving the economic performance for operators.

In light of the above, it is also worth noting that the Australian Government entered into a project partnership with industry in 2006 (involving BP Australia, IMPCO Technologies, Cootes Transport and Melbourne University) with the aim of developing a greenhouse friendly dedicated LPG engine for heavy duty applications over 400 hp (Rare 2006). The project was conducted under the auspices of the AFCP, but was subsequently terminated by agreement between the parties owing to the inability of the partnership to develop an engine that delivered a 5% GHG benefit relative to conventional diesel.

4.4.1 Potential fleet application

LPG is the only alternative fuel with any significant penetration into the Australian market, powering approximately 3% of the total vehicle fleet, mainly passenger and light commercial vehicles (ABS 2009).

However, LPG's low energy density means LPG vehicles have reduced carrying capacity compared with conventional liquid fuels.

4.4.2 Key challenges

Compared with the European experience, the potential carbon benefits of using LPG in light vehicle applications have not been realised in Australia. Use of LPG in heavy vehicle and bus fleets is also limited. A key factor in this failure is associated with the suboptimal performance of Australian LPG technologies relative to European technologies (COAG 2008). This anomaly is unlikely to be corrected without further investment in LPG engine and conversion technology, such as developing liquid injection technology for LPG engines.

A secondary challenge concerns the limited availability of LPG in Australia. While Australia exports significant volumes of LPG, this export volume is predominantly excess volumes of butane that cannot be used by Australian transport owing to current fuel standards applying to LPG (LPG Australia 2008). That is, the use of domestically produced LPG is limited by the availability of propane in Australia.

Experience from the AFCP suggests that the use of LPG in commercial vehicles does not guarantee better carbon outcomes over conventional diesel, with many of the vehicles tested under the program showing no advantage over an equivalent diesel engine, and some showing a significant disadvantage (COAG 2008).

From a global perspective, the availability of LPG is limited and is unlikely to replace petrol or diesel (King 2007). Further, as LPG is a petroleum-based fuel it will become increasingly vulnerable to oil price volatility as supplies of 'easy' oil decline (Jamison Group 2008).

4.4.3 Likely timing

LPG will continue to be an immediate option for use in passenger cars and light commercial vehicles. However, limited availability of heavy vehicle LPG technologies suggests it is unlikely to be a viable alternative to conventional transport fuels in the near term.

4.5 Hydrogen (and fuel cell vehicles)

Hydrogen has significant potential to be used as an alternative for conventional fuels in vehicles equipped with either traditional internal combustion engines or new generation fuel cells.

Hydrogen-powered vehicles produce no carbon emissions at the tailpipe. However, the production of hydrogen is currently highly energy intensive involving the reforming of water, coal, gas, crude oil or biomass (DoE 2009). As a consequence, hydrogen will only deliver significant carbon benefits if the electricity used in the production process is derived from renewable sources or is equipped with carbon capture and storage.

4.5.1 Potential fleet application

A review of available literature indicates hydrogen production, storage and heavy vehicle drivetrain technology is rapidly developing. In the US, Europe and China there are increasing numbers of hydrogen bus trials and pilots of gaseous internal combustion and fuel cell electric engines.

Between 2004 and 2007 the Western Australian Government studied the performance of a first generation hydrogen bus. The trial indicated that CNG and diesel buses are likely to continue to be more greenhouse efficient than hydrogen buses until hydrogen is produced using renewably sourced or CCS enabled electricity and advancements in fuel cell technology (DPI 2008).

In a cost-benefit analysis, hydrogen buses were found to be up to 80% more expensive to refuel compared with conventional diesel or CNG prices in 2006. Further, the analysis also indicated that without reforms to transport pricing to internalise the external costs of current road transport (e.g. costs to health and environmental sustainability) hydrogen bus technology is likely to remain economically unviable for the foreseeable future (Owen & Cockcroft 2006).

While there are significant carbon benefits from hydrogen-powered vehicles fuelled by low-carbon sourced hydrogen, it does currently entail significant cost. Costs include reduced passenger capacity so that the hydrogen storage units can be accommodated, higher purchase prices of the vehicles, and higher running and maintenance costs (NREL 2009).

4.5.2 Key challenges

The current challenges to the use of hydrogen in transport are numerous and substantial. A key challenge, particularly for the Australian market, is the current high cost of hydrogen bus technology. From a carbon emissions perspective, this translates to a high cost of abatement compared with other fuels such as CNG, and other technologies such as hybrid-diesel electric buses (NREL 2009). As greater numbers of hydrogen vehicles are produced, it can be expected that these initial costs will decrease.

Other challenges that are likely to delay the uptake and adoption of hydrogen-fuelled road vehicles in Australia include the high cost of building dedicated hydrogen production and refuelling infrastructure, limited access to renewable or low emission energy sources for hydrogen production, practical difficulties associated with fuel handling, decreased carrying capacity, fuel cell longevity, and fuel quality and safety regulation (COAG 2008, NREL 2009).

4.5.3 Likely timing

While some sources suggest hydrogen will be a viable fuel for transport in Australia before 2020 (CSIRO 2008), these views are very much in the minority and appear to rely on optimistic perspectives on the likelihood of the required technological breakthroughs in vehicle technology occurring in the next 5–7 years. Even with such breakthroughs, the slow turnover rate of the Australian bus fleet would result in slow adoption of the new technology into the market.

The majority consensus within the transport industry, including that of the authors, is that hydrogen will remain a demonstration and niche technology for some time yet, and is not likely to be used as a general transport fuel until around 2030, if at all (COAG 2008, Jamison Group 2008, Climate Group 2009). Increasingly, the focus is on electric-powered vehicles which could have the potential to be modified for hydrogen fuel cells at some time in the future (Jamison Group 2008).

4.6 Other energy sources

4.6.1 Electricity

Electric vehicle technology is rapidly accelerating, driven largely by governments in response to energy security and climate change concerns, and by automotive industry fragility following the global economic downturn in late 2008. The focus is primarily on electric passenger vehicles but work on developing electric heavy vehicles such as urban buses is also underway.

Similar to hydrogen, the potential carbon benefits associated with electric-powered vehicles comes from the use of renewably-sourced power to recharge the batteries as well as providing a medium to store renewably-generated power such as wind (frequently generated during off-peak periods) for electricity demand.

The challenges associated with greater use of electric buses are also similar to hydrogen technology. They include pre-commercialisation of electric bus technology, high cost of the technology, battery limitations and range limitations. It is unlikely that electricity will be an available alternative fuel for the bus and heavy vehicle sector until after 2020, and then it is likely to be limited to urban applications only.

4.6.2 Solar (vehicle-generated)

The solar-powered vehicle, which has been around for some time, has been restricted almost entirely to the enthusiast market due to practical issues around cost, size and weight, convenience and reliability. Without significant advances in photovoltaic technology it is unlikely that solar energy will ever be used as the sole source of engine power.

There is the potential for existing hybrid vehicles to utilise solar energy as an additional power source. The 2009 model Toyota Prius has the option for solar panelling to power a ventilation system to reduce internal vehicle temperatures when parked (Toyota 2010). Aftermarket solar kits involving an additional solar charging system that provides increased electric driving range and up to 29% improved fuel economy are also available for the Prius (SEV 2008). However, these kits are considered to be suited to a niche market and not cost effective for the general consumer.

4.6.3 Compressed air

The potential for compressed air to be utilised as a source of energy to power vehicle drivetrains has received limited attention, although some developers have indicated that models will be available to consumers in the short term. For instance, the French-based company MDI (Moteur Developpment International) has developed a series of prototypes, running either entirely on compressed air and offering a range of 150 km, or on a hybrid system using conventional fuels at speeds above 50 km/h. The hybrid system is expected to achieve a fuel economy of 2 L per 100 km, with a potential range of 2000 km.

In early 2008, the inventor of the technology announced a joint venture with a New Zealand firm to produce cars and power systems at a plant in Melbourne, with an estimated start date of 2010 (Jamison Group 2008).

There is a large amount of scepticism surrounding the technology owing to energy density issues and the sources of the energy used to compress the air. In spite of the zero emissions at tailpipe, there is a significant pressure placed on upstream energy in compressing the air required to fuel the car. Similar to hydrogen, compressed air is an energy storage medium rather than a source and, as such, faces the same life cycle and infrastructure barriers that are likely to place a significant hold on its development in the short to medium term.

5 Drivetrain improvements

5.1 Fully electric drivetrains

An electric bus uses electric motors and motor controllers instead of an internal combustion engine. The earliest examples of electric buses were trolley buses powered by two overhead electric wires. Recently, the electric bus concept has focused on the storage of energy for the motor in battery packs (e.g. lithium-ion battery) which are located on board the vehicle to provided greater route flexibility beyond the constraints of fixed infrastructure.

In some cases, ultra capacitor technology can be used as secondary storage for quick recharging of smaller amounts of electricity to supplement batteries. However, while ultra capacitors are normally designed to be partially charged en route (at a bus stop), battery storage systems are designed to be fully charged at a bus depot or where the bus service terminates.

An alternative concept to emerge that tackles the problem of slow battery recharging is to exchange the entire battery pack at specialised exchange stations. These stations would operate in a similar way to the current system used to exchange domestic gas cylinders at many service stations. Such a system would of course require cooperation between bus manufacturers, battery suppliers and battery exchange operators to ensure a standardised vehicle interface to allow for easy exchange.

5.1.1 Fleet application

A key characteristic of metropolitan buses is that they have predictable routes that can allow efficient planning of electric recharging locations. Charter buses that require flexibility, or regional coaches that require greater range, would of course be less suitable. Regenerative braking systems which are integral to most electric vehicle systems (whereby some of the energy that would normally be lost is recovered by the braking system) also makes electric buses more suited to urban bus applications where energy recovery can be maximised in stop-start driving.

Another consideration for the adoption of electric drivetrains is the increasing horsepower and air-conditioning requirements that operators of modern bus fleets face. So far, electric buses that require range comparable to conventional buses do not meet the gross vehicle weight rating classification for conventional buses and therefore need to be lightweight and/or offer limited passenger capacity. This is reflected in the growing number of niche electric bus applications for airport passenger transfer, city shuttle and closed campus travel – most of which have quite short-range requirements.

There are currently fully electric buses in operation in several countries including China, Canada, the USA and other European countries. Many more vehicles are being developed and are undergoing commercial trials.

In Australia, Adelaide City Council is piloting the electric-powered Tindo bus on urban routes. The bus's batteries are recharged using grid power supplemented by capacity of solar power generated from photovoltaic panels installed on the bus depot buildings (Adelaide City Council 2008. The bus is air-conditioned, can carry up to 40 passengers and has a range of 200 km. It was manufactured in New Zealand by Designline International.

Another example is the BCI Proma battery electric coach offered for charter services by Crown Coaches and which can carry 28 passengers (Crown Coaches 2010).

Tindo electric bus

Crown Coaches electric bus

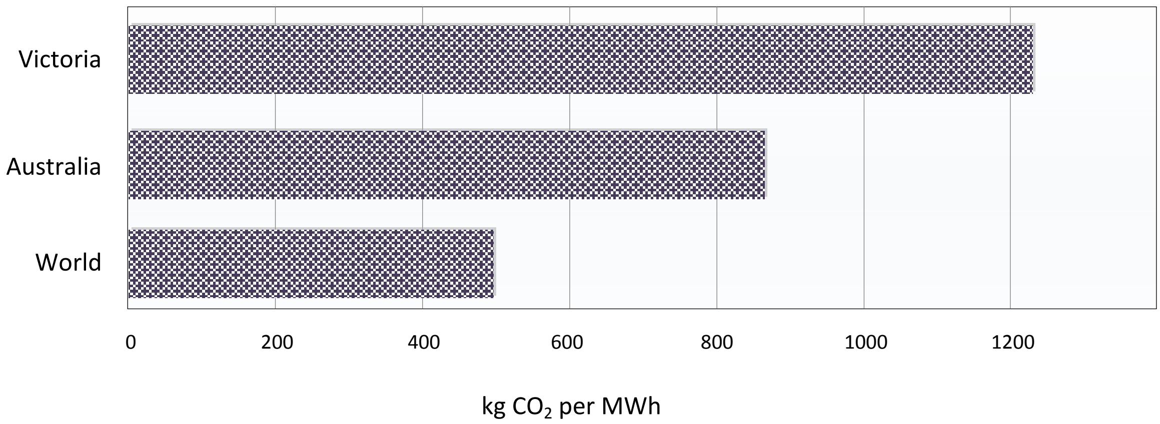
An electric drivetrain that demonstrates a different approach to recharging is the use of battery-super capacitor buses. Since 2006, fourteen super capacitor buses have been operating in a 5 km circular route in the old city centre of Shanghai and they have recently been used at the 2010 Shanghai Expo. These buses use energy stored in large on-board super capacitors that can be charged in 30 seconds when they stop at a bus station with an overhead electric charger. This enables the bus to run for 3–6 km depending on the payload and electrical load, including air-conditioning (UNEP 2010). After the success of the first batch, another five buses were put into service on another route in Shanghai in mid-2009.

To date, super capacitor buses have only been demonstrated for city centre routes with short stopping intervals.

5.1.2 Estimated emissions (and fuel benefit)

Electric vehicle technology is often referred to as zero emissions technology. While the air quality benefits are excellent at the point of energy use (at the bus), the zero emissions description is misleading. The air quality and life cycle greenhouse emissions from electric buses are heavily influenced by the electricity generation technology. Vehicle batteries charged from coal-derived electricity would have an emissions footprint that is definitely not zero, and far larger than if they were charged from solar, wind or some combination of renewables.

Given Victoria's heavy dependence on brown coal for electricity generation, the carbon dioxide emissions intensity of electricity is significantly higher than the national and world averages (Figure 5.1) and poses both challenges and opportunities to the shift to electric buses.



Source: IEA 2007b and National Greenhouse Accounts (NGA) Factors 2010

Figure 5.1

Carbon dioxide emissions intensity of electricity production (2008)

Looking beyond the variability in emissions depending on electricity source, fully electric vehicles can deliver a significant benefit to operators compared with conventional fuels, this being fuel cost savings (Jamison Group 2008). Adelaide City Council found a 50% decrease in fuel costs associated with the Tindo electric bus compared with a diesel bus (Adelaide City Council 2008). Covering 55,000 kilometres in its first year of operation, the bus saved the Council more than 14,000 L of diesel and 70,000 kg of CO_2-e. Similarly, Sinautec estimates its super capacitor buses have one-tenth the energy cost of a diesel bus, which would result in lifetime fuel savings of about $200,000 over a 12-year vehicle life. However, the higher unit cost has so far deterred wider adoption of the technology. The battery life has improved to about eight years, but weight and size of the battery is still considered an issue (UNEP 2010).

Overall, if existing electricity generation from coal is replaced with renewable energy sources to improve the life cycle greenhouse emissions from electric buses or electric vehicles in general, the higher cost associated with renewable electricity generation (in excess of the expected rise in conventional fuel costs) may reduce the financial appeal of electric vehicles.

5.1.3 Estimated costs

As with most new technologies, the overall financial performance of electric vehicles over the entire vehicle life depends on the rate of payback of the higher capital cost of these technologies, the service life, mileage and any difference in maintenance costs (e.g. battery costs).

While electric buses can produce major fuel cost savings compared with conventional vehicles, very little information on maintenance cost data is currently reported. This may be because the electric drivetrains in many of the buses in service to date have been developmental and their maintenance requirements are higher than would be expected in fully commercialised production vehicles and therefore are not comparable to conventional diesel vehicles.

5.1.4 Timeframe to realisation

Announcements such as increasing numbers of electric bus trials and the planned replacement of the entire bus fleet in Montreal with electric buses by 2025 (STM 2009), may lead the public to believe that electrification of the bus fleet is accelerating rapidly. In reality, widespread adoption of electric buses beyond niche applications may still be some years away.

The City of Montreal Plan extends well beyond the life of new buses introduced into its fleet and will be responsive to the availability and development of electric bus technology. In the interim, Montreal will take smaller steps to trial smaller electric buses and buses powered by overhead wires on some of the city's busiest routes. In addition, from 2012 all bus purchases will be either hybrids or electrics. The long-term recharging strategy that Montreal is looking to adopt involves the use of fast-charge buses that can store enough energy for a 20 kilometre journey, with 10–15 minutes recharging at each end of the route.

Overall, the key factors to be overcome before more widespread adoption of electric buses is likely relate to a reduction in cost and more certainty on recharging access and technology. Even for government-supported programs such as the Shanghai Expo Electric Bus Scheme, which can be well controlled in a defined area, buses need to be specifically matched to local conditions and infrastructure.

5.2 Electric hybrid drivetrains

A hybrid powertrain is one that uses a combination of power sources to move a vehicle. For bus applications this is typically a diesel-powered combustion engine and an electric motor coupled to a large capacity battery. The electric motor can act as either the primary or supplementary source of tractive effort depending on the hybrid configuration chosen.

The primary purpose of a hybrid powertrain is the recovery of braking energy (regenerative braking). In a normal vehicle all the kinetic energy associated with the vehicle’s motion is lost as heat when the brakes are applied. In a hybrid vehicle, the electric motor absorbs this kinetic energy by generating electricity and storing it in a large capacity storage battery. This energy can then be used to accelerate the vehicle via the electric motor and replace some of the fuel that would normally be required. As a general rule of thumb, a hybrid system can recover about 50% of the braking energy.

There are two principal types of hybrid vehicle – a parallel hybrid and a series hybrid. A parallel hybrid vehicle is one where the vehicle's wheels can be driven by either the internal combustion engine or the electric engine, or both systems together. A series hybrid is one where the vehicle's wheels are driven solely by the electric motor with a smaller internal combustion engine effectively acting as a generator to power the batteries for continued operation of the electric motor.

It is worth noting that while hybrid vehicles generally comprise an electric motor and an internal combustion engine, other forms of hybrid vehicles include a hydraulic hybrid and a pneumatic hybrid. Concept vehicles demonstrating these systems have appeared in recent years. As the predominant use of hydraulic hybrid technology is for garbage trucks (most of which require a hydraulic system for compaction) and concrete agitators, this technology is generally not suited to bus applications. As a result, hydraulic hybrid bus technology is not considered in great detail in the following section.

5.2.1 Fleet application

The principal barrier to the increased adoption of hybrid bus technologies in Australia is associated with the performance uncertainty surrounding the real-world operation. Analysis of past hybrid bus trials shows a marked variation between manufacturer estimates of fuel savings and the real-world fuel savings realised by the vehicle operator, leading to market confusion about the quantum of fuel savings that can be genuinely realised by using hybrid vehicles. This variation can be explained by a number of factors discussed below.

STOP-START INTENSITY OR ROUTE PROFILE

The primary advantage of a hybrid bus over a conventional bus is its ability to recover kinetic energy under braking conditions and to then reuse this energy for the next acceleration phase or short-distance cruise. A well-configured hybrid should be able to capture and reuse 50% of the vehicle's kinetic energy.

However, when a bus is cruising there is little opportunity to recover significant amounts of energy. The extra weight of the hybrid system will increase rolling resistance and the extra parasitic loads for battery cooling and hybrid system control will increase electricity consumption – as a result, fuel consumption can increase. If the bus is used on a route that has few stops or low road congestion, the extra fuel used to carry and operate the hybrid system may be more than the fuel saved during stops and restarts. The break-even point in terms of stop-start intensity will vary depending on the type of hybrid powertrain employed.

An understanding of the interaction between the driving profile and the chosen hybrid system architecture is extremely important if hybrid technology is to be effectively deployed. Poor route assignment could substantially affect the return on investment in hybrid technology.

PAYLOAD

Because the primary objective of the hybrid system is kinetic energy capture and reuse, increasing payload will increase energy recovery proportionally. It can therefore be expected that the difference in fuel consumption between a standard bus and a hybrid bus will increase as payload increases, as long as the stop-start intensity is sufficient to cover the extra mass and parasitic loads of the hybrid system. It would therefore make sense to assign hybrid buses to routes that have higher load factors.

TOPOGRAPHY

Climbing a hill is analogous to accelerating a bus, and controlling the descent of a bus through braking is analogous to stopping. A hybrid bus should therefore have an advantage over a conventional bus as the energy spent climbing the hill can be recovered during the descent. This advantage is held only as long as the storage capacity of the battery is significant in comparison to the potential energy difference between the top and the bottom of the hill. If the hill is very long, not all the potential energy released during descent can be stored in the battery for reuse and the extra fuel used hauling the hybrid system to the top of the hill will be more than the fuel saved on the descent.

Some advanced hybrid systems use GPS technology and topographical information to modify the control of the hybrid system to compensate for hilly terrain. On the hill climb, the system depletes the battery more than usual so that there is more capacity to recover energy on the descent. A series hybrid with a large capacity battery is probably more suited to hilly terrain than a simple parallel hybrid.

For these reasons, topography needs to be considered when selecting hybrid architecture and assigning buses to particular routes.

WARM CLIMATE OPERATION

A factor that is less understood relates to the influence of air-conditioning systems on the mode of operation. In warm climates such as in Australia, where the air-conditioning system is operating constantly, the operation of the air-conditioning system is likely to result in the hybrid vehicle spending longer periods in internal combustion engine operation than would be the case if the air-conditioning system were turned off. As a consequence, hybrid buses characterised by long periods of air-conditioning operation will deliver lower overall fuel savings – albeit that there is currently very little data on the magnitude of this reduction.

5.2.2 Estimated emissions (and fuel benefit)

Reduced fuel consumption is commonly the primary objective of introducing hybrid buses into the fleet. As vehicle GHG emissions are directly proportional to fuel consumption, there will also be reduced emissions from using a hybrid powertrain. The reduction in fuel (and GHG emissions) will depend on the factors discussed previously and will mean that the fuel savings of a hybrid can vary substantially.

Fuel savings are of direct financial benefit to the bus operator and can be used to offset the additional cost of hybrids. Crown Coaches' preliminary hybrid testing reported a fuel economy of 3.73 km/L compared to 2.75 km/L for conventional buses (Crown Coaches 2010).

To accurately forecast fuel consumption, a great deal needs to be understood about the technology to be employed and the intended duty cycle. Under some operating conditions a hybrid bus may be no more efficient than a well-designed and maintained conventional bus.

The use of a hybrid powertrain also has the potential to provide public health benefits by reducing emissions regulated under the Australian Design Rules, such as carbon monoxide, hydrocarbons, oxides of nitrogen (Nox), particulate matter and smoke. The key reasons are:

- NOx production is a function of combustion temperature and pressure. By supplementing peak power demands with stored electrical energy, the engine is not forced to operate at high combustion temperatures and pressures;
- smoke, particulate matter, hydrocarbons and carbon monoxide production are a result of incomplete combustion and are a function of engine load and speed, so will also be improved if some load is taken off the engine and engine speed is reduced;
- it is possible to use a smaller engine and to keep it within its most efficient operating range.

5.2.3 Estimated costs

Hybrid bus technologies have a substantial cost premium when compared with conventional bus technologies. Based on discussions with the vehicle operators and manufacturers, the cost premium for a strong hybrid is approximately $200,000 and typical industry estimates of the cost premium range from 50–75% higher than conventional technologies.

The cost premium of hybrid bus technologies is principally attributable to the cost of providing the additional electric drivetrain. A hybrid bus retains all the existing components in a standard bus, albeit with a range of modifications, but the electrical drivetrain requires the addition of three major new components: the energy storage system (ESS), the electric motor and the power electronics.

The hybrid system also requires more complex control architecture to manage the entire powertrain system smoothly. Added to these component costs are the amortised design and development costs which are still being spread across a relatively small number of delivered vehicles. Component level costs are hard to determine but an estimate can be made based on published information on the unit costs of the key components. Using this information it is possible to estimate the cost breakdown of the various types of hybrids (Table 5.1).

Table 5.1 does not include estimates for profit, amortised engineering development or manufacturing tooling, which will increase the end user cost substantially, particularly in the early years. Once the upfront investment has been recovered, manufacturing volumes increase and more competition exists between manufacturers, the premium for a hybrid bus can be expected to drop to numbers that are closer to those in Table 5.1.

Table 5.1 Estimate of component costing for different hybrid configurations (44-seat bus)

Component	Unit	Unit cost ($)	Series		Simple parallel		Complex parallel	
			Size	Cost[1] ($)	Size	Cost[1] ($)	Size	Cost[1] ($)
Engine	kW	100	–150	–15,000	–20	–2,000	–20	–2,000
ESS[2]	kWh	1,500	50	75,000	10	15,000	20	30,000
Generator + inverter	kW	285	100	28,500	0	–	0	–
Electric motor(s) + inverter[3]	kW	285	120	34,200	44	12,540	80	22,800
Transmission	speed	2,000	–5	–10,000	0	–	4	8,000
Total				112,700		25,540		58,800

1 Negative numbers for engine power and transmission speeds indicate reduction from a standard vehicle and hence lower price. Cost estimates based on discussion with Cummins Australia.

2 ESS cost based on quote for prototype Li-ion 20 kWh battery pack including battery management.

3 Electric motor and power electronic cost based on quote for high-end permanent magnet motor and matching controller.

Apart from comparing the capital cost of hybrid bus technologies, a further consideration is the net difference in costs associated with maintaining a hybrid bus – relative to a conventional bus.

Relative to conventional technologies, hybrid vehicles deliver both increases and reductions in elemental maintenance costs. The principal areas where the maintenance costs of hybrid technologies differ from conventional technologies can be summarised as follows.

- **ENGINE**. Generally speaking, the engine will be operating at lower loads and speeds and should therefore be under less stress and be subjected to less thermal cycling. The stress on some engine components should be lower and therefore high mileage failures may be less frequent. Additionally, the lower particulate matter emissions should result in lower oil contamination and less engine wear, or longer intervals between oil changes.
- **TRANSMISSION**. Moving to a hybrid transmission generally involves the elimination of the torque converter from the transmission. Torque converters generate heat within the transmission and contribute to the ageing of the transmission oil. A hybrid transmission should therefore run cooler than a conventional automatic transmission, resulting in longer oil change intervals.
- **ELECTRIC MOTOR**. The electric motor is a very simple device from a mechanical perspective. It typically has only one moving part and no sliding contact between components. Temperatures are controlled by either oil or coolant circuits within the stator windings. A well designed electric motor should essentially be maintenance free, apart from checking the coolant.

- **POWER ELECTRONICS**. Modern power electronics are essentially solid-state electronic devices. They should require no regular maintenance apart from checking that the coolant circuit is filled and free of air.
- **VEHICLE BATTERIES**. The on-board batteries are a major cost element, and their life can be substantially influenced by ambient and radiant heat. Past international experience with batteries suggests that a battery pack may need to replaced up to five times over the standard 25-year life of an urban bus. The current high replacement cost of these battery packs is sizeable enough to negate the fuel savings delivered by a hybrid vehicle, particularly when these vehicles are required to operate in very warm environments.
- **BRAKES**. A conventional bus uses a combination of friction brakes and a hydraulic retarder to slow the vehicle to a stop. A strong hybrid system should have the ability to bring the vehicle to an almost complete stop using regenerative braking, except in an emergency or in slippery road conditions. Less powerful hybrids will use a combination of friction and regenerative braking and will potentially have slightly higher brake wear than a strong hybrid. The variations in hybrid architecture may result in significantly different brake wear and maintenance requirements.

Limited long-term experience with hybrid bus technologies and uncertainty about the life of on-board batteries makes it difficult to draw definitive conclusions about the net impact on maintenance costs.

5.2.4 Timeframe to realisation

It is expected that electric hybrid technology will become more cost effective as production volumes increase and more manufacturers develop the technology (COAG 2008, King 2007). Although most current electric hybrids are of the parallel type, it is widely believed that series hybrids will become more dominant and eventually replace parallel hybrid systems.

Limited progress has been made in the adoption of hybrid bus technology in Australia, which lags behind progress in other countries. While the reasons for this anomaly can be partly attributed to the small size of the Australian bus market and its consequent low level of attractiveness for global bus manufacturers, there are a number of other significant barriers to the market adoption of this technology in Australia. These include:

- market confusion (information failure)
- uncertainty of real-world outcomes (performance uncertainty)
- the high additional capital cost of technology
- current operational constraints imposed by national regulations on mass and dimension limits.

A review of the current availability of hybrid vehicle technology in Australia reveals that three systems are currently being actively marketed for sale into the Australian bus and coach industry:

- **DESIGNLINE** – Series hybrid technology. A small diesel engine provides electrical power through a dedicated generator. The engine's only function is to provide electrical power. All other ancillary services (such as air-conditioning) are provided through electrical devices coupled to the ESS. This minimises the size of the combustion engine and also enables the vehicle to operate in full electric mode for short distances. This bus performs at its best on routes with high levels of traffic congestion and stop density. On linehaul routes it will prove to be less efficient than a conventional bus due to the energy losses associated with converting the mechanical energy of the engine into electrical form and then back into mechanical form.
- **VOLGREN–ALLISON** – Two-mode parallel hybrid powertrain. This bus uses engine-shaft power to drive all ancillary services and simplifies the design of the bus but forces the combustion engine to run continuously. The two-mode arrangement should minimise the losses associated with steady-state cruising and will be more tolerant of short-term cruising at suburban or highway speeds. This bus model is currently operated by the Grenda Bus Company and runs on outer suburban routes in Melbourne's east. This bus is also part of the Hybrid Electric Bus Operational Assessment Program.
- **BCI–EATON** – Simple parallel hybrid. This bus uses an Eaton hybrid system coupled to a Cummins engine. Compared to the other two vehicles listed above, this bus has a relatively small hybrid system and a simple layout. A 44 kW peak electric motor is sandwiched between the engine and it is coupled to a relatively small Li-ion ESS which weighs less than 100 kg with an estimated capacity of less than 10 kWh. In addition to employing a hybrid powertrain, BCI have focused on mass reduction to offset the extra mass of the hybrid system (estimated to be between 150 and 200 kg).

Analysis of the current hybrid vehicles market in Australia suggests that a number of additional manufacturers either have plans to make hybrid bus technology available in the near future, or they already sell hybrid engine technology in overseas markets. The following operators currently sell hybrid bus technology overseas and have planned or potential availability in Australia:

- **ALEXANDER DENNIS** – Series hybrid technology. Introduced more than 1300 hybrid buses into operation over the last 10 years in New York, San Francisco, Toronto and London.
- **VOLVO INTERNATIONAL** – Parallel hybrid technology. Volvo 7700 released into the European market in early 2009. Past trials of this technology in Europe have revealed fuel savings of up to 35% in congested city operation and the vehicle is one of the few commercial vehicle hybrid systems with idle-off capability.
- **SCANIA** – Series hybrid technology. Six buses trialled in Stockholm from May 2009

It is expected that hybrid drivetrain will be available more widely in most vehicle categories within ten years (King 2007, COAG 2008).

5.3 Mechanical hybrid drivetrains

In addition to electric hybrid drivetrains described above, some bus trials have been undertaken using mechanically-based hybrid systems that do not require batteries for energy storage.

A mechanical hybrid drivetrain is equivalent to the more common hybrid electric system in that it can recover braking energy, provide supplementary power for better acceleration and reduce fuel consumption markedly. As with electrical hybrids, mechanical systems are broadly classified as parallel or series configurations.

In a mechanical hybrid system, hydraulic accumulators, rather than the batteries typical of electrical hybrids, are used to store energy. Alternatively, clutches can be used to transfer energy to a flywheel which can store energy in a rotating mass.

5.3.1 Fleet application

The main determinant of suitability appears to be whether sufficient energy can be recovered from braking to offset the disadvantages of carrying the system's additional weight. As such, this technology is not considered suitable for regional buses and coaches as the brakes are not used frequently enough to justify the additional weight (and resultant sacrifice in payload) of using hydraulic hybrid systems.

The most obvious bus applications are therefore those that involve frequent stop-start duty cycle but vehicle weight must also be taken in to account for the following reasons:

- lower losses in converting mechanical to electrical energy allow hydraulic hybrid systems to recover up to 80% of the vehicle's original kinetic energy during braking
- the greater power density of hydraulic systems compared to electrical systems means they are 'recharged' more quickly each time the brakes are applied, and discharged more quickly during acceleration.

In 2006 Eaton tested a system called Hydraulic Launch Assist (HLA) on two buses operating in China. The system was originally developed by the Ford Motor Company and Eaton Corp for Ford's F-series pick-up trucks. The success of the trial led to a 2008 collaboration with Beiqi Foton Bus Company to produce thirty production hydraulic hybrid buses for Guangzhou Yiqi Bus (EV World 2008).

Eaton and Ford are also currently trialling an HLA shuttle bus as part of the US Army's HAMMER (Hydraulic Hybrid Advanced Materials Multifuel Engine Research) project aimed at reducing fuel consumption in military ground vehicles.

5.3.2 Estimated emissions (and fuel benefit)

The Eaton-developed HLA system used in the China bus trial realised fuel savings of up to 27%, and the regenerative braking effect of hydraulic hybrids was also expected to extend the life of braking systems and reduce the need for brake system maintenance.

5.3.3 Estimated costs

Hybridisation requires the addition of two systems (drive/recovery and storage) and the integration of these with the vehicle's existing drivetrain. This incurs additional weight and costs. Based on the size experience with Ford's HLA system used in pickup trucks, capital costs could be approximately 15% higher than a conventional bus and would add over 200 kg of weight.

5.3.4 Timeframe to realisation

While there is anecdotal evidence of trials in China and the US, there are currently no commercialised options for mechanical hybrid systems available.

6 Vehicle improvements

6.1 Improved vehicle aerodynamics

The power required to overcome aerodynamic drag and move an object through the air increases cubically with speed, so that doubling speed requires eight times the power (e.g. power to overcome drag at 100 km/h is eight times the power required at 50 km/h). At highway speeds, up to half of the energy consumption of a bus is used to overcome aerodynamic drag.

Limited information is available in the literature to illustrate the benefits of aerodynamic improvements specifically on buses. However, linehaul trucks achieve improved aerodynamic efficiency by fitting aerodynamic devices (commonly referred to as 'fairings') that target a number of areas where drag is most prevalent. By extension, such devices could also benefit buses.

Of the devices suited to trucks, gap treatments are clearly not applicable to coaches and it is unlikely that skirts or under-body treatments would be suitable due to the already low ride height of most coaches. Additionally, active flow control is only likely to be beneficial on already streamlined profiles. Coaches, however, typically have bluff bodies.

Therefore streamlining is likely to provide the most potential for buses. However this is normally incorporated in the design of new vehicles by the manufacturer (and therefore not considered as a major opportunity in this section). Boat tail fairings are another option but there are few products available to be retrofitted to existing vehicles by commercial retrofitting organisations.

6.1.1 Fleet application

A higher drag coefficient leads to higher energy losses and higher corresponding fuel consumption. As the drag increases with speed, the application of aerodynamic drag reduction measures is most effective on buses with frequent high-speed operation (e.g. regional coaches).

6.1.2 Estimated benefit (fuel and emissions)

Aerodynamic drag can be reduced in a number of ways. US Transportation Research Board (TRB 2010) cites the following potential fuel savings associated with various aerodynamic drag reducing measures in motor coaches (Table 6.1).

Table 6.1 Potential fuel savings from aerodynamic treatment

Item	Potential savings
Boat tail	3–5%
Vehicle streamlining	3–4%

6.1.3 Estimated costs

Costs for aerodynamic devices vary according to the specific fairing piece. Based on equivalent pricing of treatments in the heavy truck segment, the US Transportation Research Board (TRB 2010) cites the following prices (Table 6.2). Due to the low manufacturing volumes of aerodynamic devices that can be retrofitted to coaches it is likely that these costs could be higher.

Table 6.2 Potential cost of aerodynamic treatment

Item	Potential cost
Boat tail	$2,000 – $2,500
Vehicle streamlining	$3,500 – $4,000

6.1.4 Timeframe to realisation

The authors did not find any Australian providers of retrofit aero kits for buses. However, the greatest opportunity for improvement is likely to be in streamlining the profile of coaches, which is an opportunity being pursued by bus manufacturers.

6.2 Ancillary equipment and accessories

Buses often require the engine to provide power for a variety of functions that include productive use (for example, compressed air equipment for lowering/kneeling of the suspension) and non-productive use (air-conditioning and lighting). Technology developments in vehicle component systems are reducing the overall energy demand for many of these functions. For example, lighting options such as high intensity discharge lamps (HIDs) and light-emitting diodes (LEDs) are available today that improve lighting efficiency by two to ten times over conventional incandescent and halogen lamps.

Such systems reduce the electrical demand on the alternator which would otherwise represent a parasitic loss of engine power. And while LEDs can increase the up-front costs of lighting by a factor of five to ten times, their far longer service life and more durable nature can significantly reduce ongoing maintenance costs and the risk of failing vehicle roadworthiness inspections.

Other vehicle systems which have traditionally relied on mechanical drive from the tractive engine (such as air compressors and hydraulic power steering) are being developed as electrically-powered systems to reduce the need for the main bus engine to provide the intended function of these systems.

There are limited current examples where these technologies have been applied in the bus industry, although it is expected that the development of battery-electric, hybrid-electric and fuel cell buses will increase the development of electrically-powered ancillaries which can be powered by stored electrical energy.

Air-conditioning represents the largest usage of energy for bus accessories, so naturally this area has received significant attention in the quest for efficiency improvements. The power demand for a bus air-conditioning system is 8–15 kW – far less than that produced by the bus tractive motor – resulting in wasted fuel if the engine is left running for the sole purpose of air-conditioning.

A range of commercial auxiliary power units (APUs) can supplement electrical systems for functions like air-conditioning which do not require the full power of the bus tractive motor. These units generally consist of small engines (2-cylinder or 4-cylinder) powered by diesel or battery-based electrical systems that maintain battery charge with a small generator.

A mechanically-driven air-conditioning compressor can also be replaced with an equivalent electrical device, as is the case with the air compressor and power steering systems described earlier. The electrical air-conditioner would typically be a high-voltage electric motor coupled to an inverter.

Using an electric air-conditioning compressor could improve efficiency because:

- an engine-driven compressor needs sufficient displacement to provide acceptable air-conditioning performance while the engine is at idle speed. Such compressors are over-sized for when the vehicle is cruising, leading to compressor cycling. An electric compressor can be correctly sized and run at the correct speed regardless of engine speed, and thus can be smaller with higher overall efficiencies;
- an electric compressor can be mounted inside the rooftop air-conditioning unit, removing the need to run long air-conditioning fluid lines from the engine compartment. This is likely to reduce system maintenance and leakage of refrigerant which has a high greenhouse warming potential (Repice & Shulz 2004).

For buses in Australia, air-conditioning improvements are likely to follow developments in the European Union and the US, with customers continuing to receive what manufacturers offer rather than driving product development innovations from here.

6.3 Transmissions

Research is currently being undertaken to understand the application of continuously variable transmissions (CVTs) for use in the trial of the Kinetic Energy Recovery System (KERS) for fitment to buses, which was announced in November by Torotrak plc in the UK (Flybus 2009). While the technology could be considered as a flywheel-based mechanical hybrid, the project is expected to be licensed through Allison Transmissions using a CVT transmission that is integral to its operation. It is targeted to deliver fuel efficiency savings of 20% and will be half the size and weight – and a quarter of the cost – of hybrid electric systems (European Motor News 2009).

Allison Transmissions also recently launched its Load-Based Shift Scheduling technology which automatically optimises gear selection between economy and performance schedules according to the vehicle’s payload and the gradient of the road.

6.4 Improved tyre technology and reduced rolling resistance

The rolling resistance of a tyre is the amount of energy that is required to get a tyre moving, and to keep it moving. There are two main contributing factors to a tyre's rolling resistance: tyre design (size, structure and materials), and operating conditions (including inflation pressure, load, alignment and temperature) (IEA 2007a). Optimum tyre design may involve reduced tread depth and more frequent replacement when compared with standard tyres.

If the amount of rolling resistance can be reduced, the amount of fuel required to move a vehicle will also be reduced. Low-rolling resistance tyres therefore offer genuine potential for fuel savings and emissions reductions across the full range of bus applications.

Reducing rolling resistance tyres have in the past raised concerns about the trade-off with traction and an increase in stopping distances. This is especially relevant for bus operators given the nature of their payload. However, the National Research Council in the US has indicated that in spite of traction impacts from modifying a tyre's tread to reduce rolling resistance, the safety consequences are 'probably undetectable' (IEA 2007a). In addition, the US Transportation Research Board's study was unable to locate any data that provided insight into the safety impacts associated with the modification of tyre tread to reduce rolling resistance (TRB 2006).

7 Opportunities assessment

Potential opportunities to reduce GHG emissions from road vehicles can be categorised under two specific strategies. The first strategy involves the increased uptake of transport fuels that have a lower carbon intensity than conventional transport fuels when considered on a full life cycle basis. By promoting the increased uptake of these alternative fuels, the greenhouse emissions of the vehicle fleet can be reduced relative to the business as usual scenario.

The second strategy involves the increased uptake of more energy efficient vehicle technologies. Such technologies range from the adoption of alternative drivetrains (e.g. hybrid electric drivetrains) to the energy saving devices for conventional internal combustion engines (e.g. AMTs and aero devices).

The information presented in Sections 4, 5 and 6 was used to develop an assessment of the key short-term and medium-term opportunities for reducing vehicle-related emissions from the Victorian vehicle fleet, in terms of alternative fuels and alternative vehicle technologies. For the purposes of this study, *short term* was defined as the next 8–10 years, and *medium term* 10–15 years. Within that timeframe the assessment comprised three elements of analysis:

- identification of the likely timing to realisation of each of the fuel and technology opportunities identified under the study;
- an qualitative assessment of the likely range of per-vehicle emissions reductions for each likely opportunity;
- identification of the current barriers to the realisation of the major opportunities and the potential strategies for overcoming them.

7.1 Opportunities for the adoption of alternative bus fuels

An analysis of the discussion in Sections 4, 5 and 6 gives rise to the following specific observations regarding the opportunity to realise fuel savings (or GHG emissions reductions where a fuel comparison is not appropriate) from the increased uptake of fuels other than diesel.

- There is an increasing body of authoritative literature which suggests that first generation biofuels (and biofuel blends) do not provide any substantial greenhouse emissions benefit relative to conventional transport fuels. In addition, the production of these fuels is likely to be limited by the combined constraints of land availability and food demands. These two factors, coupled with rising feedstock prices for producers and the foreshadowed imposition of a federal fuel excise on all alternative fuels from 1 July 2011 (in accordance with the *Fuel Tax Act 2006*), are likely to result in the reduced cost-competitiveness and reduced availability of this fuel in the future.

- Second and third generation biofuels are likely to figure prominently in the future transport energy mix in the longer term. The commercial availability of these fuels will, however, depend upon substantial breakthroughs in production technology. As a consequence, these second generation fuels are not expected to be available in significant volumes before 2025.
- CNG is being increasingly used in urban bus fleets in Australia and a small number of light-duty rigid trucks (which often share the characteristic with many bus operations of operating 'back to base'). There is significant uncertainty about the greenhouse benefit of some natural gas engines when considered on a life cycle basis (Garnaut 2008, COAG 2008). This uncertainty relates to the lower combustion efficiency of spark-ignited natural gas engines relative to compression ignition diesel engines (Orbital 2007) and the operating cycle of the vehicle.
- Interest in LNG fuel for long-haul and back-to-base truck operations has been growing, but adoption has been largely constrained by a lack of widespread availability of the fuel, lack of factory-supported engine options on new trucks, and the cost of engines that are available. The situation with respect to all three of these limitations is expected to improve considerably in the next 12–18 months. However, for most bus operations (except perhaps interstate and regional coaches) LNG fuel holds no advantage over CNG and is also more costly. An evaluation of net greenhouse benefit from LNG yields mixed results, due largely to variations in the combustion efficiency of different natural gas add-on technologies.
- Substantial research and development work has been undertaken in respect of the commercial production of synthetic diesel using CTL and GTL. When considered on a life cycle basis, the emissions generated by CTL and GTL fuels are significantly higher than conventional transport fuels, ranging from 50–90% higher (depending on energy source) based on the results of a life cycle analysis conducted by Rare. The future commercialisation of these transport fuels is likely to be constrained by the need to develop more carbon-efficient manufacturing processes and/or develop carbon capture and storage technologies. As a consequence, synthetic fuels are unlikely to be available for transport use in the short to medium term.
- LPG is already widely used in sections of the passenger car market, helped by federal government incentives for the purchase of LPG conversions. However, its use in the truck and bus segments has been limited (apart from niche applications relying on aftermarket bi-fuel systems that range from crude to relatively sophisticated). However, none of the major vehicle manufacturers is developing systems for application in the truck or bus segments. The outlook for this fuel in the bus sector is therefore considered of little significance.
- Hydrogen (and fuel cell vehicles) are still very much in the prototype stage and the advancement of this technology for transport is complicated by major challenges relating to the cost, complexity, fuel handling and absence of low carbon production sources. The majority consensus within the transport industry, including that of the authors, is that hydrogen will not be available as a transport fuel in the next 25–30 years, if at all.

Given the focus of the main study to which this report contributes – that is, to evaluate the degree to which alternative fuels offer a practical alternative to diesel in the bus fleet – it must be concluded that there are few realistic alternatives for buses other than CNG (for metro or back-to-base operations) and LNG (for buses requiring a longer range, such as interstate and regional coaches).

This conclusion takes into consideration four primary criteria that need to be satisfied for a fuel to be considered a viable and realistic alternative:

1 **ECONOMICALLY COMPETITIVE** – resulting in a life cycle cost the same or lower than conventional diesel, and incurring the same or lower fuel costs on an energy-equivalent basis (since it is unlikely that an operator would opt for a fuel costing more than the business as usual option).

2 **OPERATIONALLY COMPETITIVE** – not requiring wholesale changes to current practice with respect to refuelling, maintenance, vehicle dynamics and handling, regulatory compliance and monitoring, and fleet compatibility.

3 **STRATEGICALLY COMPETITIVE** – requiring long-term supply of the fuel to be stable and abundant, and minimising vulnerability to future oil price escalation.

4 **ENVIRONMENTALLY COMPETITIVE** – not entailing significantly higher emissions of regulated exhaust pollutants or greenhouse emissions (on a life cycle basis), considering the high likelihood of a future carbon emissions price signal and regulatory or reporting requirements.

7.2 Opportunities for the adoption of alternative drivetrains and vehicle technologies

Applying these four criteria to the material presented in Sections 5 and 6 provided an insight into the most likely drivetrain and vehicle technologies that could potentially be deployed to reduce emissions from the bus fleet, taking into consideration the challenges that will need to be addressed if these opportunities are to be realised.

In considering criteria 1 and 4, the source material in Sections 5 and 6 was used to develop estimates of the per-vehicle emissions benefit of the six drivetrain and technology opportunities identified in the study. The estimated benefit was calculated in terms of the likely benefit, considering the variable application of each technology and the influence of real-world duty cycles. The results of the analysis are summarised in Table 7.1.

Analysis of the results in Table 7.1 gives rise to the following specific findings with respect to the greenhouse emissions benefit of short-term vehicle technology opportunities.

- The greatest technology opportunity for the reduction of greenhouse emissions from buses lies in the adoption of hybrid electric drivetrains (short term) and fully electric drivetrains (medium term). These two technologies can achieve fuel and emissions reductions of up to 60% for hybrids that are well matched to the real-world duty cycle of the vehicle, and up to 80% for electric buses if the electricity is sourced from renewable sources.
- Hybrid drivetrains constitute the most significant near-term opportunity for the bus segment, given the current and emerging availability of models with this drivetrain. However, care needs to be taken in specifying the hybrid system to accurately match the duty cycle requirements of the bus if fuel and emissions savings at the upper end of the spectrum hope to be achieved.

- Mechanical hybrids and other drivetrain or gearbox technologies are not expected to present a viable opportunity for buses in the near term, owing largely to the lack of products being developed for buses in this area.
- Low rolling resistance tyres present a current, cost-effective and reliable pathway for small reductions in both fuel use and emissions. Products are available in a range of sizes and the perceived disadvantages have been addressed by manufacturers over time.
- The opportunity to reduce fuel consumption and emissions from the use of electrically powered ancillaries is limited in the near term. As hybrids and electric buses are further developed, these ancillaries are expected to enhance and enable the benefits of those drivetrains.

These findings are summarised in Table 7.2 where each opportunity is evaluated for likely timeframe to implementation in each of the three bus categories: scheduled metropolitan services, scheduled regional and linehaul (coach) services, and charter services.

Table 7.1 Estimated GHG benefit of selected bus drivetrain and vehicle technologies

Technology option	Potential savings
Electric drivetrains	+80% to –50%*
Hybrid electric drivetrains	+60% to –5%†
Mechanical hybrid drivetrains	up to 27%†
Ancillary equipment & accessories	up to 10%†
Low-rolling resistance tyres	4% to 8%
Improved vehicle aerodynamics	up to 5%‡

* Potential savings depend on emissions intensity of electricity source: 100% for renewable generation, minus 50% for brown coal

† Potential improvement highly dependent on duty cycle matching

‡ Only applicable for high average speeds

Table 7.2 Estimated suitability and timeframe to realisation for alternative fuels and technologies in segments of the bus fleet

Fuel	2010			2015			2020			2025			2030		
	Metro	Region	Charter	Metro	Region	Charter	Metro	Region	Charter	Metro	Region	Charter	Metro	Region	Charter
Biofuels	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓
LPG	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
CNG	✓	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
LNG	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✓
Synthetic diesel	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓
Hydrogen & fuel cells	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
Solar & compressed air	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Electric hybrids	✓	✗	✗	✓	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓
Mechanical hybrids	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗
Electric vehicles	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✓

7.3 Implementation considerations

Combining the insights in Table 7.2 suggests that the most likely opportunities for short-term adoption in the national bus fleet are:

- natural gas fuel: using CNG storage on back-to-base urban buses or those with relatively short-range requirements; and using LNG on regional and interstate applications where they coincide with proposed public refuelling networks;
- hybrid electric drivetrains;
- low rolling resistance tyres.

Electric buses represent an additional opportunity in the medium to long term; however, this opportunity will be limited to specific urban applications. Furthermore, the greenhouse benefits achievable with this technology will only be fully recognised when the electricity used to charge these vehicles can be sourced from renewable sources (or the carbon captured and stored). In reality, electricity generated from renewable resources is likely to be limited in the near future, and the viability of commercial-scale carbon capture and storage is still far from certain.

Of the three short-term opportunities, low rolling resistance tyres is the only one currently available with a significant market history. In fact it is no longer considered an emerging or potential opportunity, but instead is considered part of the common suite of options on offer to operators at the time of tyre replacement.

For the remaining opportunities, a qualitative assessment of the likely barriers to their market introduction was undertaken in order to identify the issues that are likely to be encountered in the adoption of these technologies within the Victorian bus industry. Much of the source material used for this assessment was derived from current literature and industry discussions (as summarised in Sections 4, 5 and 6). A discussion of the key findings of this analysis is presented below.

It should be noted that none of the fuel and vehicle technologies (popularly promoted as being substitutable for conventional fuels) constitutes an opportunity for wholesale replacement of diesel across all sectors of the diesel bus fleet. Rather, the study team believes that the more likely pathway for alternative fuels will involve the simultaneous advancement of a number of technologies. Each technology will be specifically suited to one or more bus segments that comprise the total fleet.

7.3.1 Natural gas fuels (CNG and LNG)

Abundant reserves of indigenous natural gas, and its current price advantage over conventional diesel fuel, are two factors that position natural gas as a viable alternative to diesel for buses, at least at a strategic level. The technical and economic viability of natural gas, at least in CNG form, has also been demonstrated in many bus applications around the country.

A degree of uncertainty remains with respect to the life cycle emissions of gas due to its operability in a range of engine types. While proponents typically claim benefits at the higher end of the scale, the actual emissions reduction varies between compression-ignition and spark-ignited systems, between different types of compression-ignitions systems, and even in different installations of the same system due to duty cycle variations. Specifically, past studies have identified the variation in tailpipe emissions of methane (for natural gas vehicles) owing to substantial differences in the combustion efficiency of methane.

Complicating the issue further, aftermarket installations of bi-fuel systems using CNG or LNG have no current agreed protocol by which to compare emissions performance with new gas or diesel engines. Rather, there appears to be an opportunity to resolve this uncertainty by establishing state-based tailpipe methane limits for aftermarket vehicle conversions. Ideally, such an agenda would be undertaken in partnership with other states to encourage uniformity in regulations on a national basis.

Notwithstanding these issues, most of the earlier limitations to adoption of natural gas as a transport fuel for buses are being progressively resolved via the planned introduction of integrated refuelling networks, wider choice of suitable engines, and the associated reduction in cost of these engines. Nevertheless, a bus operator proposing to run vehicles on CNG would still currently need to construct a refuelling facility and navigate options for both gas supply and cost.

7.3.2 Hybrid electric drivetrains

There are two principal barriers to the increased adoption of hybrid drivetrain technologies in the Victorian and Australian bus fleets. The first challenge relates to the additional capital cost of these vehicles relative to equivalent conventional vehicles (Section 5).

The second barrier relates to the limited availability of hybrid vehicles within the rigid truck and bus segment. A limited range of hybrid buses have undergone trials in the eastern states of Australia, with mixed results.

Lessons from trials to date suggest that both the bus supplier and the operator need an intimate understanding of the real-world duty cycle in which the bus will operate, and that this understanding should drive the specification or choice of hybrid for that application (with respect to type, strength, payload, etc). In essence, the only pathway to achieving the maximum potential benefits of the system is to carefully match the strengths and weaknesses of the technology to the demands of the application.

7.3.3 Fully electric drivetrains

The analysis completed for this study gives rise to two major observations with respect to the likely availability of electric drivetrains in the near future. The first is that significant development is occurring in electric drivetrain technology for buses, but that this technology will, for some time into the future, be suitable only in narrow or niche urban applications. Depending on the energy storage system employed, it may require the development of significant infrastructure for charging. The second is that the environmental performance of these vehicles is almost entirely dependent upon the sourcing of electricity generated by renewable resources.

The development of electric buses and charging infrastructure for Australia, and Victoria in particular, is therefore likely to be dependent upon the resolution of the following specific issues.

- **DEVELOPMENT OF A PROTOCOL (OR STANDARDS) FOR ELECTRIC VEHICLE BATTERIES**. Given past challenges associated with the harmonisation of vehicle technologies (such as toll collection technology), it is suggested that there is an early need to develop a standard or protocol for the safe and efficient operation of batteries for electric vehicles. Such a standard might be developed along similar lines as national fuel standards legislation by specifying performance criteria with respect to battery life, recharging time, materials handling and safety issues such as the physical integrity of the battery. Standards Australia is currently developing a strategy with the assistance of industry which is investigating the need for standards covering a range of EV issues including batteries, recharging equipment and safety. However, it is unknown whether heavy vehicles will be included in the scope of that work.
- **ACCELERATION IN THE DEVELOPMENT OF RENEWABLE ELECTRICITY SUPPLIES IN VICTORIA**. The greenhouse and air quality benefit of electric vehicles will require the development of renewable energy sources for transport use. This is of great significance for Victoria, which has one of the most emissions-intensive electricity sectors of any state. In the face of likely increased demand for renewable energy arising from the introduction of a future emissions trading scheme (e.g. Carbon Pollution Reduction Scheme), there is likely to be a significant increase in national demand for renewable energy. There may therefore be an opportunity for demonstration projects targeting the delivery of renewable electricity infrastructure for road vehicles (e.g. cogeneration facilities in the vicinity of high-rise commercial and residential buildings).
- **DEVELOPMENT OF STANDARDS AND REGULATIONS FOR ELECTRIC VEHICLE CHARGE POINTS**. As with battery technology (described above), there will be a need for the development of standards and regulations governing the location, design and operation of vehicle charge points. This is also included in the work being undertaken by Standards Australia; however, it remains to be seen how different heavy vehicle charging points will be from those for light vehicles.

Appendix A

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Appendix B

Glossary

ABBREVIATIONS AND ACRONYMS

ADR	Australian Design Rules
AFCP	Alternative Fuels Conversion Program
AMT	automated manual transmission
APU	auxiliary power unit
CH_4	methane
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
CTL	coal to liquids
°C	degree Celsius
ESS	energy storage system
g	gram
G	giga
GHG	greenhouse gas
GTL	gas to liquids
h	hour
HFC	hydrofluorocarbons
HID	high intensity discharge
HLA	Hydraulic Launch Assist
IEA	International Energy Agency
J	joule
k	kilo
LED	light emitting diode
LNG	liquefied natural gas
LPG	liquefied petroleum gas
M	mega
N_2O	nitrous oxide
p.a.	per annum
PFC	perfluorocarbons
psi	pounds per square inch
SF_6	sulphur hexafluoride
t	tonne
T	tera
UNFCCC	United Nations Framework Convention on Climate Change
W	watt

GLOSSARY

ALTERNATIVE FUELS CONVERSION PROGRAM
An Australian Government program that ran from January 2000 to June 2008. It supported key commercial fleet operators to trial selected alternatively fuelled engines in order to assess the commercial viability and environmental performance of these engine systems in heavy vehicles and to demonstrate their feasibility to the wider transport industry. Over 60 projects were funded through the program, covering both bus and truck fleets. The fuels/technologies included CNG, LNG, LPG, hydrogen fuel cell and hybrid diesel/electric.

BASELINE
A projected level of future emissions against which reductions by project activities could be determined, or the emissions that would occur without policy intervention.

B5
A blend of 5% of biodiesel with diesel

BI-FUEL VEHICLE
Vehicles with multi-fuel engines capable of running on two fuels. On internal combustion engines one fuel is gasoline or diesel, and the other is an alternate fuel such as natural gas (CNG), LPG or hydrogen. The two fuels are stored in separate tanks and the engine runs on one fuel at a time. Bi-fuel vehicles have the capability to switch back and forth from gasoline or diesel to the other fuel, manually or automatically.

BIOFUELS
Fuel derived from plant material, e.g. wood, straw; and ethanol from plant matter.

BIOMASS
Term to describe the resource of energy stored in plants and animals or released during their use or processing, including as a by-product or waste. Biomass is a renewable energy source and the main source of stored energy for the majority of the human race.

BUSINESS AS USUAL
An estimate of future patterns of energy consumption and GHG emissions which assumes that there will be no major changes in attitudes and priorities. Continuing current practices with no additional action to reduce or mitigate GHG emissions.

BUTANE (C_4H_{10})
A highly flammable, colourless, odourless, easily liquefied gas.

CARBON CONSTRAINED ECONOMY
An economy in which there are limits imposed on emissions of GHGs, whether through direct legislation or economic instruments.

CARBON DIOXIDE (CO_2)
A naturally occurring gas that is also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic GHG that affects the earth's temperature.

CARBON DIOXIDE CAPTURE AND STORAGE
A technology aimed at reducing GHG emissions from burning fossil fuels during industrial and energy-related processes. It involves the capture, transport and long-term storage of carbon dioxide, usually in geological reservoirs deep underground, that would otherwise be released to the atmosphere.

CARBON DIOXIDE EQUIVALENT (CO_2-E)
A standard measure that takes account of the different global warming potential of different GHGs and expresses the cumulative effect in a common unit.

CARBON MONOXIDE
A colourless, odourless highly poisonous gas formed by the incomplete combustion of carbon or a carbonaceous material, such as gasoline.

COMPRESSED NATURAL GAS (CNG)	A high-pressure state of natural gas used in vehicle operation. CNG has a diesel equivalence (i.e. energy density basis) of approximately 1.1 cubic metres per litre of diesel.
DRIVETRAIN	The components of an automotive vehicle that connect the transmission with the driving axles and include the universal joint and drive shaft.
DUAL-FUEL ENGINE	An engine that utilises diesel and natural gas simultaneously, as opposed to switching between fuels. High proportions of natural gas are substituted for diesel when the engine is operating beyond low engine revolutions per minute.
ETHANOL	An alcohol obtained from the fermentation of sugars and starches or by chemical synthesis. It is the intoxicating ingredient of alcoholic beverages, and is also used as a solvent, in explosives, and as an additive to or replacement for petroleum-based fuels.
E10	An ethanol petrol blend comprising 10% ethanol and 90% petrol by volume.
FISCHER-TROPSCH PROCESS	The Fischer-Tropsch process is a catalysed chemical reaction in which synthesis gas (syngas), a mixture of carbon monoxide and hydrogen, is converted into liquid hydrocarbons of various forms. It is commonly referred to as gas to liquids (GTL) and coal to liquids (CTL),
FOSSIL FUEL	Any naturally occurring carbon-containing material which when burned with air (or oxygen) produces (directly) heat or (indirectly) energy. Fossil fuels can be classified as solid fuels (coals), liquid fuels (petroleum, heavy oils, bitumens) and gaseous fuels (natural gas).
GLOBAL WARMING POTENTIAL (GWP)	A factor describing the radiative forcing impact (degree of harm to the atmosphere) of one unit of a given GHG relative to one unit of carbon dioxide.
GREENHOUSE GAS	The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).
HYBRID DRIVETRAIN	The hybridisation of two or more different power sources in the same vehicle. The general term describes a range of significantly different types that can use mechanical, electrical and chemical systems to store and deliver energy, with each possessing distinct performance advantages in a particular application. The most commonly used arrangement utilises an electric motor coupled with an internal combustion engine (together creating an electric hybrid). This is the type of system found in most commercially available hybrid vehicles and many of those currently undergoing development.
HYDROFLUOROCARBONS	Compounds containing only hydrogen, fluorine and carbon atoms. They were introduced as alternatives to ozone-depleting substances in serving many industrial, commercial and personal needs. HFCs are emitted as by-products of industrial processes and are also used in manufacturing.

INTERNATIONAL ENERGY AGENCY

The IEA acts as energy policy advisor to 27 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to coordinate measures in times of oil supply emergencies. As energy markets have changed, so has the IEA. Its mandate has broadened to incorporate the *Three E's* of balanced energy policy making: energy security, economic development and environmental protection. Current work focuses on climate change policies, market reform, energy technology collaboration and outreach to the rest of the world, especially major consumers and producers of energy like China, India, Russia and the OPEC countries.

KYOTO PROTOCOL

An international treaty negotiated under the auspices of the UNFCCC. It entered into force in 2005. Among other things, the Protocol sets binding targets for the reduction of GHG emissions by developed countries. It includes individual emissions reduction commitments for developed countries to be met within the first commitment period of 2008-12.

LIFE CYCLE ANALYSIS

Assessment of the sum of a product's effects (e.g. GHG emissions) at each step in its life cycle, including resource extraction, production, use and waste disposal.

LIQUEFIED NATURAL GAS (LNG)

A cryogenic state of natural gas used in vehicle operation. LNG has a diesel equivalence (i.e. energy density basis) of approximately 1.62 litres per litre of diesel.

LIQUEFIED PETROLEUM GAS (LPG)

A mixture of hydrocarbon gases used as a fuel in heating appliances and vehicles, and increasingly replacing chlorofluorocarbons as an aerosol propellant and a refrigerant to reduce damage to the ozone layer.

METHANE (CH_4)

After carbon dioxide, the most important GHG is methane. Although methane doesn't match the volume of carbon dioxide emissions, methane traps over 21 times more heat per molecule compared to carbon dioxide. Methane originates from several sources including the burning of fossil fuels, agricultural activities and the decomposition of residues.

NITROUS OXIDE (N_2O)

Nitrous oxide is a major GHG. Despite its relatively small concentration in the atmosphere, it is the third largest GHG contributor to overall global warming, behind carbon dioxide and methane.

OXIDES OF NITROGEN (NOX)

These oxides are emitted from the combustion of vehicle fuels and react in the atmosphere with hydrocarbons in the presence of sunlight to form petrochemical smog.

OZONE (O_3)

At ground level (in the troposphere), ozone is considered an air pollutant that can seriously affect the human respiratory system. It is a chemical oxidant and a major component of photochemical smog.

PARTICULATE MATTER

Particulate matter classified as having an aerodynamic diameter less than 10 microns (PM10) or an aerodynamic diameter less than 2.5 microns (PM2.5), including adsorbed polycyclic aromatic hydrocarbons.

PERFLUOROCARBONS (PFCS)

A group of man-made chemicals composed of carbon and fluorine only. These chemicals (predominantly CF_4 and C_2F_6) were introduced as alternatives, along with hydrofluorocarbons, to the ozone-depleting substances. In addition, PFCs are emitted as by-products of industrial processes and are also used in manufacturing.

PHOTOVOLTAIC

Photovoltaic refers to a technology which uses a device (usually a solar panel) to produce free electrons when exposed to light, resulting in the production of an electric current.

PROPANE (C_3H_8)

A colourless, gaseous hydrocarbon found in petroleum and natural gas. It is widely used as a fuel.

REGENERATIVE BRAKING

Regenerative braking is a system in which the electric motor that normally drives a hybrid or pure electric vehicle is essentially operated in reverse (electrically) during braking or coasting. Instead of consuming energy to propel a vehicle, the motor acts as a generator that charges the on-board batteries with electrical energy that would normally be lost as heat through traditional mechanical friction brakes. The accompanying friction (electrical resistance) assists the normal brake pads in overcoming inertia and helps slow the vehicle. All hybrid and electric vehicles use regenerative braking to generate electricity to help recharge their batteries.

SULPHUR HEXAFLUORIDE (SF_6)

According to the Intergovernmental Panel on Climate Change, sulphur hexafluoride is the most potent GHG that it has evaluated, with a global warming potential of 22,200 times that of carbon dioxide when compared over a 100-year period.

SYNTHETIC DIESEL

Diesel produced via the Fischer-Tropsch process using biomass, natural gas or coal. Synthetic diesel is a paraffin product without sulphur.

TAILPIPE EMISSIONS

The products of burning fuel in a vehicle's engine, emitted from the vehicle's exhaust system.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCC)

Signed in 1992 at the Rio Earth Summit, the UNFCCC is a milestone Convention on Climate Change treaty that provides an overall framework for international efforts to mitigate climate change. The Kyoto Protocol is a protocol to the UNFCCC.