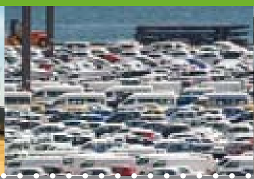
Fuelling Future Passenger Vehicle Use in Australia

An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia • The Electric Vehicles Revolution






Reports of Jamison Group to
NRMA Motoring & Services
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The Jamison Group

The Jamison Group was established by NRMA Motoring & Services following the company's Alternative Fuel Summit in 2006 and comprises eminent scholars in the fields of energy and transport – Mark Diesendorf, John Mathews, David Lamb, Nick Burke and Graeme Pearman.

The Jamison Group's first report *A Roadmap for Alternative Fuels in Australia: Ending our dependence on oil* was published in 2008 and can be found at http://www.mynrma.com.au/cps/rde/xchg/mynrma/hs.xsl/jamison_report.htm.

Mark Diesendorf

Dr Mark Diesendorf has contributed to this project under his business name, Sustainability Centre. Previously he has been a Principal Research Scientist in CSIRO and Professor of Environmental Science at University of Technology Sydney. He is the author of many scholarly papers, consulting reports, popular articles and media reports on ecologically sustainable development and renewable energy. His most recent books are 'Greenhouse Solutions with Sustainable Energy' (2007) and 'Climate Action: A Campaign Manual for Greenhouse Solutions' (2009).

John Mathews

Professor John Mathews is the Eni Chair of Competitive Dynamics and Global Strategy at LUISS Guido Carli University, in Rome, and Professor of Strategy at Macquarie Graduate School of Management, Macquarie University, Sydney. He is the author of the books 'Strategizing, Disequilibrium and Profit' (2006), 'Dragon Multinational: A New Model of Global Growth' (2002), and 'Tiger Technology: The Creation of a Semiconductor Industry in East Asia' (2000). Specialising in technology and innovation, John has published papers on the renewable energy industries, alternative fuels and biofuels industries. He has worked internationally with UNCTAD, UNIDO and with the World Bank, and was a Visiting Scholar at the Rockefeller Foundation Study Center at Bellagio, in Italy, in September 2004.

David Lamb

David Lamb worked for 28 years in the motor industry in Australia and around the world. From 1992 to 2003 he was Chief Executive of the CSIRO Australian Automotive Technology Centre and was responsible for the CSIRO Low Emission Vehicle project that resulted in two hybrid electric show cars. The aXcessaustralia car was exhibited around the world to carmakers. He was also responsible for the collaboration between CSIRO and Holden Australia to produce the Holden ECOommodore Hybrid electric car, first shown publicly in May 2000. Now retired from CSIRO, David consults on automotive technology and strategy.

Graeme Pearman

Dr Graeme Pearman was Chief of the CSIRO Division of Atmospheric Research, 1992–2002. He has contributed over 150 scientific journal papers primarily on aspects of the global carbon budget. More recently he has published on the relations between energy futures, national security, emergency services and human behaviour and the climate change issue. He is now a private consultant contracting to private and public sector organisations and Adjunct Senior Research Fellow, School of Geography and Environmental Science, Monash University. Graeme's work has been internationally recognised with numerous distinctions and medals. He is a board or advisory committee member to numerous organisations including START International (Washington), Climate Institute (Sydney) and the South East Australian Climate Initiative (Canberra). He was science adviser to Former US Vice President Al Gore during his visits to Australia in 2007, 2008 and 2009. He provides major Australian companies and governments with briefings (210 in 2007-2009) on climate change science and sustainability as part of their risk assessments around the climate change issue.

The authors would like to thank Dr Nick Burke for his significant contribution to the Natural Gas sections in the *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia* report.

Foreword

In 2008 the Jamison Group launched its first independent report *A Roadmap for Alternative Fuels in Australia: Ending our Dependence on Oil*. The report presented a clear guideline to securing a greener, less volatile transport energy future for Australia.

Since that time there has been considerable progress globally on developing alternative fuels and ending their dependence on fossil fuels, yet Australia's progress has been slow.

Two years on and the Jamison Group's hard work continues with this second independent report, which highlights the challenges facing Australia in regards to this critical issue. If nothing is done to develop new energy sources now, Australia will fall further behind.

The risk of a looming $25 billion oil trade deficit alone should be enough to shock decision-makers in Australia into action.

This report outlines the challenges we face, but also provides solutions to secure Australia's transport energy future. The NRMA hopes this report will lead to the formulation of a national transport fuel strategy for Australia.

I commend the Jamison Group members, Mark Diesendorf, David Lamb, John Mathews, Nick Burke and Graeme Pearman, for their continued efforts in this field. As long as they continue to ignite debate there remains hope that Australia will succeed in securing its transport energy future.

Wendy Machin
President, NRMA Motoring & Services

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Overview

The first Jamison Report was published by NRMA Motoring & Services in July 2008 with the opening statement, "Australia's oil dependence must end".

The oil price shock of 2007 and 2008 passed temporarily when the global financial crisis struck, but it showed, as predicted in the 2008 Jamison Report, the impact on everyday costs of transport and the flow-on effect on food prices. It was a wake-up call for us to reduce our dependency on oil. Now lulled back into complacency by lower oil prices and a weak US dollar shielding us from the more recent, albeit small, rises in the world price of crude oil, there is no evidence we have learned from the experience.

This earlier report is now updated in two new reports from the Jamison Group which show that Australia's transport fuel security will remain vulnerable over the next ten years at least, until alternatives to oil are available to cover basic needs. They show that the alternatives cannot be made available quickly enough, and in sufficient quantities, to make an immediate difference. They also recognise that single solutions are likely to be inadequate to address the challenges, and by themselves, might expose the nation to unnecessary risk.

Alternatives to oil are examined in the first report *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia*. It shows that:

- Changes to behaviour that reduce fuel demand could make a significant contribution to national fuel needs;
- Biofuels may also contribute to national fuel needs if accompanied by long-term comprehensive planning and incentives;
- Natural gas could make an important transitional contribution, but massive infrastructure implications need to be recognised and dealt with, and competing demands for gas may limit its contribution;
- The establishment of new vehicle fuel consumption standards, commensurate with those of the European Union, would underpin both a resurgence of the vehicle manufacturing industry and contribute to reducing national fuel demand; and
- The promotion and support of the development of the electric car option should also be a significant part of the future.

The likely future transition from internal combustion to electric drive cars is discussed in more detail in the second report, *The Electric Vehicles Revolution*, so titled as to reflect the Jamison Group's view that rapid changes in this direction are about to dominate the future of the motor car. Australia needs to be prepared to face the changes arising from increased use of electric vehicles and, indeed, profit from them.

A particular issue is the future sourcing of electricity and this can only be addressed within the context of a national energy plan that includes transport energy.

The urgency with which the nation must address issues of oil dependency reflects several emerging challenges. These can be addressed concurrently with important co-benefits, through a holistic policy development discussed in these reports. These include:

- Ensuring the future mobility of industry, commerce and the citizenry;

- Coping with a potentially massive balance of trade deficit associated with oil imports that could reach $25 billion per annum in 2015;
- Managing the potential risk of disruption to imported fuel supplies;
- Meeting the targets for greenhouse gas emission reduction; and
- Lowering the impact of motor vehicle emissions on community health.

Introduction

When reviewing outcomes since the first Jamison Report, it is most worrying that Australia is no closer to having a strategic plan to deal with a possible or probable reduction in the world's oil supplies. Instead, the Federal Government and the wider community have continued to assume that oil will remain available, despite a continuing decline in the amount of new oil discovered, a continuing fall in Australia's oil production since 2000 and a potentially rapid rise in demand as developing nations aspire to our levels of energy use. Aside from the issue of cost, the potential risk is that imports will grow from 55% to more than 80% over the next decade, which may represent a crippling cost to our economy, especially if anticipated rises in cost materialise. This is a serious risk, yet we still don't have a national transport fuel plan.

A portfolio of actions

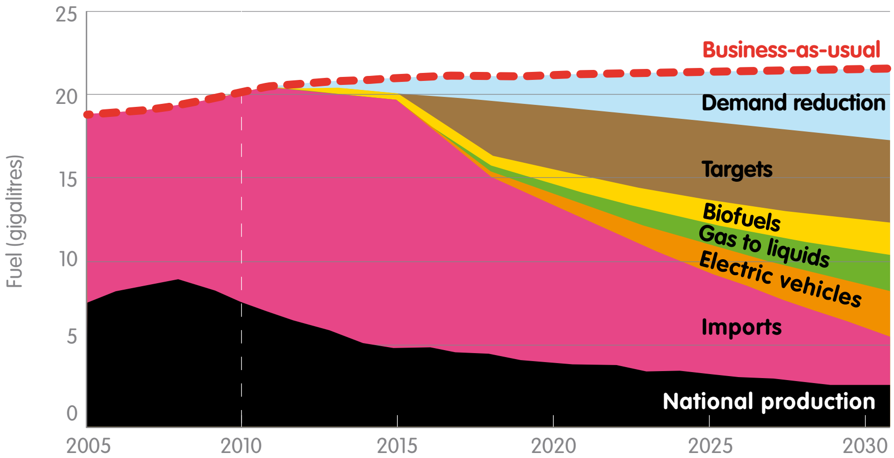
The Jamison Group is of the view that there is no single solution to the provision of future motor vehicle fuels that simultaneously addresses the issues of mobility, the balance of trade deficit, disruption to imported fuel supplies, reductions in greenhouse gas emissions and the impact of the car on community health. We have thus made preliminary investigations into a series of options and built these into a notional portfolio for fuelling passenger vehicles in Australia. Contained in this portfolio is not a prescription of what should happen, nor a prediction, but rather, a balanced set of actions reflecting our judgment of how the future could evolve.

The five components of the portfolio are:

- Demand Management strategies to reduce private transport fuel use including measures aimed at improving trip efficiency, reducing unnecessary trips, promoting and supporting public transport, cycling and walking, together with appropriate urban planning;
- Targets for lower fuel consumption in oil-powered vehicles, which are expected to be met through a combination of technological changes such as down-sizing, hybrid-electric drive, weight reduction, conversion to diesel or LPG fuels, and the like;
- Biofuels from various feedstocks;
- Natural gas and liquefied petroleum gas used in internal combustion engines, stored in the vehicles in either gas or liquid form; and
- Electric vehicles, using electricity generated from renewable sources.

The list is not necessarily complete. Other alternatives could conceivably emerge during the decades under consideration, but the five we have selected are realistic. We have provided estimates of what might be achievable

Figure 1. Volume of liquid fuels required over time to meet anticipated increased demand for car transport with the possible contribution to demand reduction due to components of the notional futures scenario. Also indicated is the contribution to fuel demand from imports and national production.



in terms of energy, fuel volume and carbon dioxide (CO_2) emissions reduction from each of these components to provide a picture of this notional future shown, for fuel volume, in Figure 1.

This figure illustrates that in the future Australia will be increasingly dependent on imported oil just to meet business-as-usual requirements. Growth in population and numbers of vehicles will exacerbate the situation. Even with the reductions that could be made possible by the five alternatives listed in the figure, it is evident that Australia will still need to import significant amounts of oil in 2030. (For further explanation of this figure and its consequences, refer to *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia*, Section 4.5.)

We consider the gap between business-as-usual (the top line) and national production (the bottom line) for 2030 to offer a dramatic wake up call as to why alternatives must be developed and implemented with the utmost priority.

Figure 1 also illustrates that, even with urgent action on the five listed alternatives, the effect on the amount of fuel – and therefore the emissions from the transport sector – is very slow to show results for the first 10 years. As we discuss in the Alternative Fuel and Technology Mix report, emissions savings are hard to come by and every alternative to oil can only offer sustainability under stringent conditions. This is likely to apply to every alternative except the avoidance of wastage and reduction of unnecessary trips. If we are to obtain security over our fuel supply and reduce the greenhouse gas emissions from the transport sector within a decade, then we must begin at once to make changes.

Fuel costs

In the months since the release of the first Jamison Report, the number of news items devoted to the price of transport fuel has fallen from the peak in 2007–08 because the Global Financial Crisis caused a sudden drop in the global demand for oil and the price crashed from around $140 per barrel to less than $40. On the other hand, despite the drop in oil price, consumer demand for lower fuel consumption cars continues. The range of low fuel consumption cars on offer in Australia has increased and it is evident that car manufacturers are increasingly promoting the fuel efficiency of their cars' engines instead of their power.

This is a welcome change, but there are signs that the market for larger vehicles is recovering, with sales of four-wheel drive vehicles increasing in recent months. It is hard to know whether this reflects a lack of environmental awareness or a failure to appreciate our vulnerability to oil price volatility or a reaction to the evident reluctance by governments to introduce strong actions

to reduce oil consumption and emissions, such as by congestion charges or mandatory fuel consumption standards.

Just as Australian motorists were protected from the full brunt of the 2007–08 oil price increases by the beneficial exchange rate against the US dollar, they have been partly shielded from recent oil price rises by a weakened US dollar. The Australian motorist has every right to feel lucky, but little reason to be confident about the future. The fall-back position, as usual, is to hope for the best and state that "She'll be right, mate".

Disruption of fuel supplies

The prospect of restricted fuel supplies resulting from the disruption to the supply of imported oil on which we are currently 55% dependent and more so each year, is an unpleasant but real possibility. We have virtually no strategic supplies of fuel oil. How ironic might it be if we had not enough fuel for our transport while we continued to ship huge amounts of natural gas energy under contract to Japan, Korea and China?

We recognise that the recommended alternatives will take time to implement. This leads us to consider what could be available in the case of a severe shortage of imported oil. Australia would have very limited ability to cope in the event of an emergency because it has no ready alternatives of sufficient scale and no national strategic fuel reserve. In such circumstances, the most readily available shhort term measures could include the use of hybrids, or natural gas from existing distribution systems, supplemented by new facilities for accepting shipments of liquid natural gas from Australian gas fields, plus the use of small amounts of additional biofuels made available by bringing on-stream all the biofuels operations that are currently either mothballed or operating at only partial capacity. Preparation for a range of alternatives must commence now.

Fuel demand reduction

Almost nothing has changed in terms of national action to secure our future in the face of potential oil shortages and dramatic and growing evidence that carbon emissions are likely to cause overwhelming changes to our climate. There are some small signs of change, mostly in the shift in public demand for more cars with lower fuel consumption, but these are not enough. We recognise that the transport fleet cannot be changed quickly and this fact is built into the analysis shown in Figure 1.

For this reason alone, changes to reduce fuel consumption and fuel use – and thus reduce emissions – need to be implemented urgently. We have not covered public transport in detail because we wanted to concentrate on the issues of most concern to motorists. However, we feel strongly that public transport, along with re-planning of our cities for higher-density population, is a significant component of demand management strategies and is the best way to serve Australian cities.

Fuel consumption targets

The average new passenger car sold in Australia in 2008 rated average emissions of 215 g CO_2/km (222g CO_2/km for all light vehicles), according to the National Transport Commission (2009). The Australian fleet level of emissions must be much higher than the above number, because only in the last couple of years has the number of high fuel consumption cars reduced in proportion and the new cars sold only represent

about 8% of the Australian car fleet. The European average for new passenger cars sold in 2008 is 153 g CO_2/km, with the Australian equivalent (215 g CO_2/km) being 41% higher. Furthermore, Europe has a target of 130 g CO_2/km already legislated. Car makers will be fined 95 Euro for each car that fails to meet the required emissions level. Australia should not be satisfied to lag so far behind Europe in carbon dioxide emissions and should not accept excuses for lagging in fuel quality standards.

For decades Europe has had a much higher proportion of small cars than Australia. Europe has consistently lived with higher fuel taxes. The relationship is clear.

Europe's mandated target is already bearing fruit in the form of prototype cars from BMW, Mazda and Volkswagen claiming very low fuel consumption in the same range as General Motors' Volt. Fiat and Peugeot-Citroën are already closer to the target than their competitors and claim they are on track towards the new levels. Some car makers are claiming to be meeting emissions-per-average-vehicle-sold levels mandated for 2015.

The Volt, General Motors' much publicised hybrid-electric vehicle on which the future of the company so much depends, promises fuel consumption of 1.23L /100 km, or less than a quarter of the fuel consumption of most small cars on today's market. That rate of fuel consumption is equivalent to 29 g CO_2/km. This illustrates the extent of reductions that may be available in the future, but there will be a need to standardise the methods of measuring and reporting because already there are challenges to the realism of the claims for the Volt, not because of the technology, but because of the method of calculation.

Electric cars

Car makers appear to have realised that electric vehicles (EVs) or hybrid-electric vehicles are an important part of the path towards reduced dependence on oil. This is welcome news, but at the same time it highlights the need for renewable electricity to fuel the new fleet. Development of EV infrastructure must go hand in hand with changes to electricity grid regulation and supportive feed-in tariffs.

Vehicles that can draw energy from the electricity grid seem attractive in concept, but without planning, they could merely add to the greenhouse problem. Infrastructure will have to be upgraded, safety standards defined and charging regimes agreed. The literature contains abundant claims for electric vehicles, some including rapid charge times, but there are few dwellings in Australia that can provide the high electric current required for fast recharging.

So far there is no sign of high-volume electric vehicle manufacture in Australia, but the potential for the new types of components, electromechanical and electronic, may open exciting new opportunities for Australian companies.

The range of opportunities and issues regarding electric vehicles has inspired us to divide our report into two sections covering electric and liquid/gaseous fuel vehicles separately.

We conclude that electric vehicles are the most likely long-term solution to Australia's future private transport demands, and that there is likely to be a wide range of types of electric vehicles and batteries. Range extenders in the form of small internal combustion engines or other forms of oil-fuelled engines may be popular and there is still a long-term possibility for hydrogen fuel cells to replace small engines.

We recognise that it will be two decades before the majority of new vehicles can be electrified and that there will continue to be applications for which traditional technologies are best suited. But hybrid-electric cars are available now and plug-in hybrids will be on the market very soon. Everything practicable should be done to accelerate their uptake.

The overall relevance of electric vehicles requires that the plan for Australia's transport future be integrated with overall energy and greenhouse gas mitigation planning and policies. Introduction of electric vehicles needs to be planned and monitored through integrated policies, incentives and regulations.

Regional differences must be recognised in the plan. For example, encouraging electric vehicles in Tasmania offers immediate fuel and emissions savings, since most electricity in that state is generated by hydro-electric means, plus a small component from wind. The plan must deal with the risk that buyers may choose electric cars purely to save money while adding to the emission load at the generating station, as has happened in the United States.

The batteries of electric vehicles can contribute to the balancing of energy supply and demand for each 24-hour period and, through connection to 'smart homes', 'smart grids' and distributed energy, could help to achieve an overall optimum use of energy resources.

Gas

The 2008 Jamison Report showed that Australia has a substantial distribution system for natural gas, largely for low-volume domestic use. On the North-West Shelf we have a massive gas well development with potential to fuel most or all of our transport demands, but this has been committed for export to other countries. By itself, this seems a rational way to capitalise on a resource that is in high demand worldwide, but in light of Australia's increasing dependency on imported oil, it could be seen as short-sighted.

Emissions reduction

We recognise that not all of our recommendations for conserving and supplementing Australian transport fuel contribute to an immediate reduction in greenhouse gas emissions. In the event of a severe oil crisis, the first task would be to keep essential transport operating. The shortage of fuel itself would reduce fuel consumption and therefore emissions. However, we believe all recommended alternatives could be, and should be, implemented as sustainably as is possible. As well, we caution against relying on unproven technologies such as carbon sequestration. Coal can never be clean.

National Transport Fuel Strategy

Our 2008 call for a national transport fuel plan remains unanswered. We renew that call, with a widened definition of 'fuel' to include electrical energy. We believe that Australia must have a national energy plan that includes transport, recognising the potential severity of the threats and the limitations of the alternatives.

Recommendations

A national transport fuel strategy is urgently needed to move Australia towards a long-term, national goal of emissions-free, sustainable transport within the overall national energy plan. Short-term, stop-gap actions that fail to fit with the long-term goals will only make things worse. The plan must have a strategy comprising step-by-step goals and measures of progress backed by supporting regulations and incentives. Voluntary targets have been shown to be subject to luck and excuses.

We recommend a portfolio approach that:

- Provides a readiness plan of short term measures (such as hybrids and gas) supported by a strategic fuel reserve;
- Addresses legislation and subsidies, removing support for business-as-usual, and introducing new legislation that will make alternatives viable – in effect, levelling the playing field;
- Legislates for electric vehicles, including gross feed-in tariffs, and upgrading electricity grids with smart technology;
- Mandates that any additional electricity generated for electric vehicles must come from renewable sources;
- Provides for demand management, improved public transport and facilities for cycling and walking, behaviour change and fuel consumption targets;
- Develops alternative fuels such as biofuels and natural gas;
- Adopts a National Energy Strategy incorporating transport energy that recognises the growing economic and fuel security threats; and
- Limits greenhouse gas emissions leading to a secure, self-sufficient and sustainable public, commercial and personal transport system.

In the first Jamison Report we offered a list of 12 steps to steer Australia towards a greener, more sustainable transport energy future. A report card on progress would not make anyone proud and so we offer a list of actions that could lead to a more sustainable transport future, including our recommendations on the rate of progress that should be targeted. The new roadmap is shown at the end of this Executive Summary.

We hope that this report contributes to the debate on this vital topic and provides realistic proposals for actions that will lead to the agreed goals. Given the will, there is every reason why, by 2030, Australia should have a transport fleet that has low dependence upon oil and provides efficient distribution of our produce and products, moves our people in large numbers efficiently and quickly and also provides sufficient personal mobility to maintain a standard of living commensurate with conservation of the planet's resources.

Roadmap

The future fuelling of Australia's motor vehicle fleet remains uncertain. This roadmap is designed to provide resilience in the face of these uncertainties and to maximise the delivery of multiple outcomes in terms of security of supply, balance of trade, human health improvement and greenhouse-gas emissions reductions.

NB. It recognised that no single action or set of actions will provide for all of the desired improvements so a portfolio approach is the best way forward.

Roadmap for the provision of future motor vehicle fuel in Australia, showing a multiple-pronged or holistic approach.

Roadmap step				2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2025	2030
1	Construct a new national transport fuel strategy	Inclusive of multiple objectives, diverse options and consistency with a revised national energy strategy		Strategy development		On-going reassessment and revision										
2	Demand management – creating choices to reduce fuel use and increase consumer and fleet uptake of new technologies	Awareness and behavioural change (% reduction from Business-as-usual – BAU)			1	2	3	4	5	6	7	8	9	10	15	20
				Public awareness campaigns and new behavioural paradigms												
		Improved public transport and non-fossil-fuelled transport		Strategic planning and infrastructure investment, providing improved accessibility and travel times; • Promotion of new infrastructure for public transport, cycling and walking • In particular, light rail and fast metros for urban centres and sub-centres • Fast heavy rail for linking urban centre and sub-centres and for intercity travel • Mixed-mode urban – plan for multiple transportation modes, in particular, support walking and cycling options												
		Haulage options		Strategy for balance between rail, air, road freight with greater rail contribution												
3	Introduce compulsory fuel consumption standards for all new cars/ vehicles	EU 130 g CO_2/km (% sales meeting target)		Announce intent				65	100	100	100					
		EU 95 g CO_2/km (% of sales meeting target)		Establish long term targets								75	85	95	100	
		Green Car Fund to rebuild Australia's automotive industry		Enhanced targeted investment			New Australian models meeting EU consumption targets					Australian manufactures globally demanded low-emissions vehicles				
4	Tax and other incentives, legislative reform to stimulate consumer and fleet demand for vehicles running on alternative fuels or propulsion systems e.g. electric vehicles	Use the Emissions Trading Scheme to build an alternative fuels and technology industry		Transport sector strategy for 2009 emissions targets				Transport sector challenged by unfolding higher emissions reductions targets						Targets met		
		Grow new alternate fuels and technologies and supporting industries e.g. smart grid and batteries	Biofuels (% 2010 fuel)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	10		
				Economic/social analysis				National/regional strategies and incentives						Mature industry		
			Natural gas	New vehicle and retrofit options for transition to a low carbon future of motor vehicles												
			Gas to liquids (% 2010 fuel)	Pilot			Operational			0.7	1.3	2.0	2.7	3.3	6.7	10
			Electric cars (% 2020 fuel)	Support manufacturers transition					0	1	1	3	3	4	8	12
		Build infrastructure needed		Set a strategy			Encourage private sector investment									
		Wind back subsidies that reinforce oil dependence		Set a strategy			Phased out subsidies			No subsidies – perverse taxations and incentives removed and co-benefits of decarbonisation rewarded						
		State Governments reform tax and tariffs		Lower registration charges for low-consumption vehicles e.g. hybrids and electric vehicles												
		Mandate the production of alternative fuels and renewable energy to meet targets		Set a strategy			Commence phasing in targets			Targets set and met						
5	Compulsory CO, NO_x, HC and particulate emissions standards					Euro V			Euro VI							
6	Research and training	Immediate and concurrent research investment relating to:		• Fuel security issues • Support and development of vehicle production strategies • Role and opportunities for government incentives and regulation • Defining health impact of emerging emissions • Use scenario development as a means of investigating multiple outcome policy development to build resilience • Training which enables skills transfer to support new technologies												

An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia: Options and Scenarios

Summary

Australia faces significant and simultaneous challenges with respect to the provision of fuels for future motor vehicle transport. These include: increased demand, diminishing national oil production, global competition for oil, potentially higher prices, balance of trade/payments, threats to security of supply, public health and limitations to greenhouse gas emissions.

This is a complex challenge. A comprehensive approach is required to ensure that Australian motorists will not only have affordable transport options in the distant future, but have access to short- and medium-term options in the event of an oil shock or increased constraints imposed by emissions trading, for example.

The Jamison Group has been tasked with producing reports to extend the original 12-step roadmap to reduce Australia's oil dependence put forward in *A Roadmap for Alternative Fuels in Australia* (2008). The first report provided a broad outline of steps required to reduce that dependence. This report strives to outline a possible direct path to such independence by evaluating a single notional scenario as one possible portfolio of alternative fuel and technology options for Australia for the next 20 years and beyond.

This alternative fuels report demonstrates that there is no single solution to our transport energy needs. It is critical that government avoids any attempt to swing wholeheartedly behind any one single fuel type. Biofuels, for example, are not our saviour. Nor will electric cars be the only form of private transport – though they could comprise the major part. And in a vast country it is not feasible for people to rely solely on public transport, although it could become a much more important transport mode in our cities. Any attempt by government to develop one fuel type only, or to address transport in an ad hoc and piecemeal fashion, will result in Australians facing continued limited transport options.

The key findings of our investigations are:

- Providing for future transport energy is a highly complex challenge with no single solution;
- A comprehensive holistic approach is required;
- This cannot occur without government intervention in the form of legislation and review of tax structures to level the playing field so that the market and industries can drive the necessary changes;
- There is great urgency – no action would be a poor policy leading to a need by 2020 to import more than 80% of our fuel demand according to growth predictions; and
- Continued reliance on fossil fuels is exposing us to environmental and significant health risks. The number of early deaths due to vehicle emissions is comparable, if not more significant, to those resulting from motor vehicle accidents.

Transport energy mix

The transport energy mix could feasibly be comprised of:

1. Electric vehicles could play an increasingly significant role making up one third of the car fleet by 2030. This would reduce the volume of liquid fuels needed by 12% below the business-as-usual fuel demand and, if the electricity is supplied by zero-emitting sources, lower the carbon dioxide (CO_2) emissions by this percentage;

2. Natural gas and biofuels can be used to extend oil use, providing transitional energy and even crisis

back-up. Gas and biofuels may contribute 10% each to the reduction of liquid fuels and a similar percentage reduction to the CO_2 emissions by 2030;

3. Demand management, including improvements in urban public transport, could lead to a reduction of fuel required below business-as-usual by 20% by 2030;

4. Fuel consumption targets and changes to transport technologies (e.g. hybrids) and infrastructure may play a major role, lowering liquid fuel demand by 23% by 2030 and CO_2 emissions by this percentage;

5. Under this notional scenario, 5 gigalitres (GL) per annum of oil would be required by 2030 compared with a projected demand of about 22 GL; that is, about one quarter of that required under the business-as-usual scenario;

6. About 40% of the reduced oil requirement could be provided domestically, lowering the vulnerability to international prices and potential supply discontinuities significantly.

Urgent government action

Considering the delays inherent in any major change in transport energy source development and implementation, the Jamison Group consider that urgent action is required on the part of government to enact the necessary legislative changes required to level the energy and transport playing field so that new technology and infrastructure changes can be truly market driven. Failure to provide the right market conditions will result in continued tinkering around the edges of transport options and Australia will arrive at 2020 with no real sustainable transport options in place. Then we will have to watch and import technology and energy that we could so easily have developed and exported ourselves.

Recommendations

Consequently, the Jamison Group recommends:

1. The Australian Government swiftly adopt a holistic approach to establishing a national energy strategy that incorporates transport to ensure resilience in Australia's energy strategy. This should include:

a. Recognition of growing economic and supply threats to fuel security from the growing demand for diminishing local and international oil production;

b. Recognition of the potential competing demands (and possible co-benefits) for various energy sources from the energy sectors and other industries;

c. Limits to greenhouse gas emissions;

d. Adoption of a portfolio approach to improve resilience of Australia's energy options;

e. Reduction of the public health and climate consequences of various energy options and moves to reduce these consequences;

f. A transport fuel reserve to hedge against oil supply or pricing shocks.

2. The first key steps in this approach should be to:

a. Develop demand management strategies to provide real alternative fuel and transport choices and so support behavioural change and reduce private transport fuel use. This includes better management of congestion, improving public transport and its interface with private transport; promotion of cycling, walking and improved urban planning; improving infrastructure and service for public transport and rail freight;

b. Establish fuel consumption targets of 130 g CO_2/km for all new motor vehicles sold in Australia by 2015;

c. Support development of electric vehicle infrastructure in conjunction with renewable energy development to power electric vehicles to ensure rapid electric vehicle uptake does not increase emissions;

d. Develop alternative fuels (including gas to liquids and biofuels) to extend oil use, provide for rural transportation and act as interim and/or emergency stop-gap measures.

e. Recognise that there is no one single option and so remove legislation, subsidies and tax structures that encourage single-solution options or continue to support business-as-usual approaches;

f. Establish a transport, energy and urban planning office within Cabinet to oversee the complex integrated development of urban planning together with public and private transport options which includes fuel energy, technology and infrastructure development.

3. Government and industry research and development are needed to:

a. Assess and support biofuel and other alternative fuel developments and infrastructure options;

b. Review and fund electrification of transport and concurrent improvement to the electricity grid including integration with other energy supply and demand sectors;

c. Support the transitioning of the Australian automotive industry and its component industries to new technology and fuel options;

d. Terminate current government incentives, subsidies and tax concessions that maintain business as usual and create barriers to development of new industries and technologies.

Developing a holistic approach

The Jamison Group stress that this is a notional portfolio based on our industry knowledge and review of current available information concerning fuel type, quantity, distribution and related infrastructure. This report is not a comprehensive research document in that it does not provide economic analysis or determine probabilities concerning the options put forward. The intention of this report is to provide a reasonable set of options that could address the transport energy challenges Australia faces and, most importantly, demonstrates the need for a holistic approach.

However, our findings are clear: Australia will face escalating balance of trade challenges to its economy; Australia needs a revised national energy strategy; there is no strategic fuel reserve in the event of an emergency; there is an inherent time lag involved in transitioning to a new fuel economy and there is no single future fuel option that will address all of our transport needs. Any attempts to 'pick a winner' will limit our transport options.

We consider instead that there is a raft of simultaneous options that must be concurrently explored. Our outlook for biofuels is limited because of land and water use issues. However, away from the cities, on farms, in mines and in remote communities, biofuel could be useful if well managed. Additionally, biofuels would be valuable in a liquid fuel crisis. However, depending upon how they are produced, biofuels may not contribute significantly to reducing greenhouse gas emissions. Finally, we may need to reassess the current expectation that vehicles sold in any part of Australia will be appropriate for use in any other part, given that biofuel and gas-powered vehicles, and shorter-range electric vehicles, may each have their respective geographic niche.

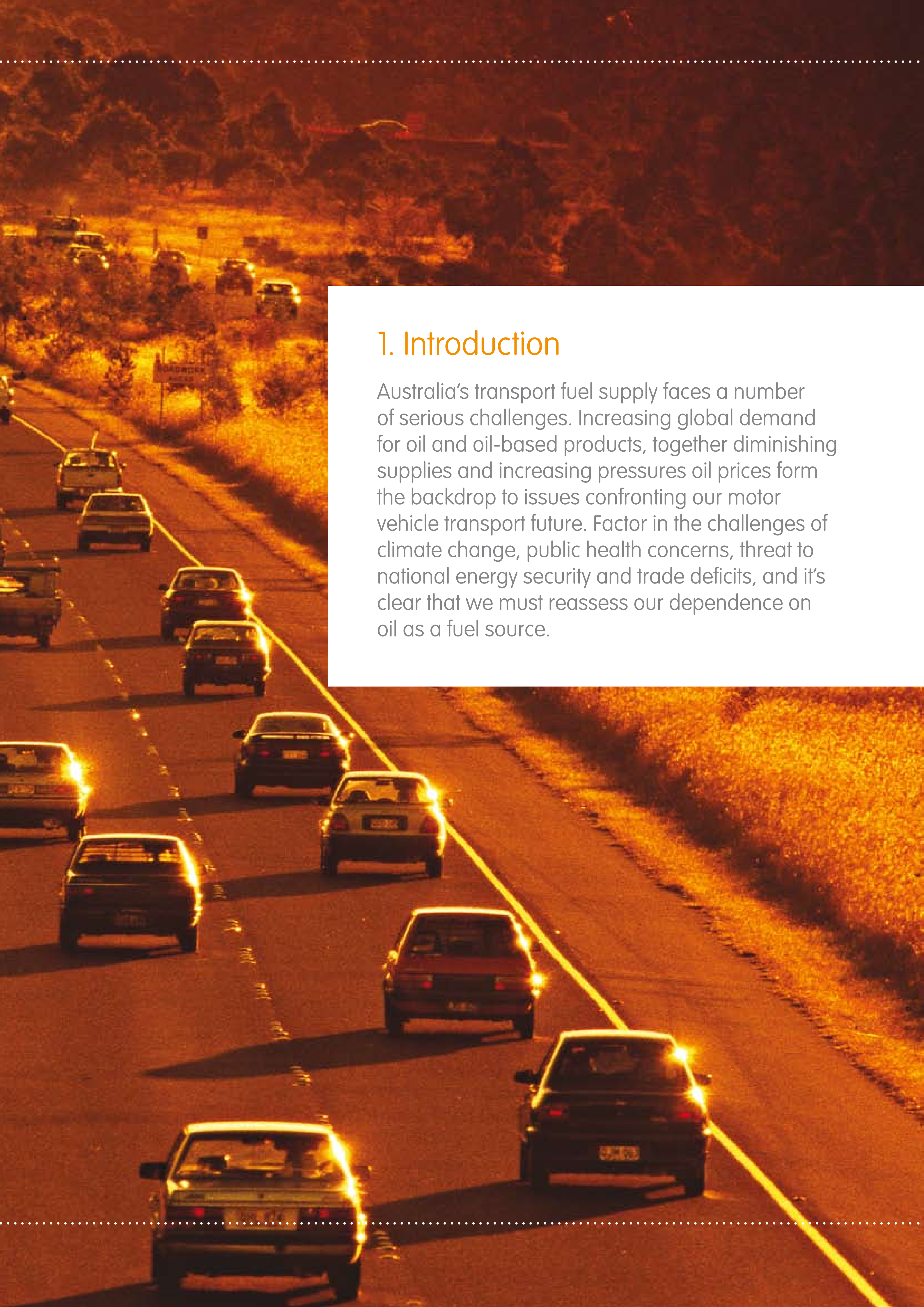
None of these options is possible without a whole-of-government approach to reviewing and altering the structures and legislation that support business as usual and create barriers to change. A review of these approaches would likely serve to engage new and established industries in competitive processes to drive the development of viable alternatives.

The challenge is massive, but Australia possesses the necessary resources to address these challenges; what is lacking is the strategy to ensure our transport future.

Roadmap

The future fuelling of Australia's motor vehicle fleet remains uncertain. This roadmap is designed to provide resilience in the face of these uncertainties and to maximise the delivery of multiple outcomes in terms of security of supply, balance of trade, human health improvement and greenhouse gas emissions reductions. It is recognised that no single action or set of actions will provide for all of the desired improvements so a portfolio approach is the best way forward as outlined in the Roadmap on page 70.

Contents



1. Introduction

Australia's transport fuel supply faces a number of serious challenges. Increasing global demand for oil and oil-based products, together diminishing supplies and increasing pressures oil prices form the backdrop to issues confronting our motor vehicle transport future. Factor in the challenges of climate change, public health concerns, threat to national energy security and trade deficits, and it's clear that we must reassess our dependence on oil as a fuel source.

This paper considers the options for future passenger vehicle road-transport fuels (light vehicles, motor cars, excluding trucks and heavy haulage vehicles) in Australia reflecting a number of factors that could well change future opportunities and perspectives in the provision of motor vehicle fuel (see Figure 1). These include growing demand, climate change, peak oil, fuel price, balance of trade, national security and air quality.

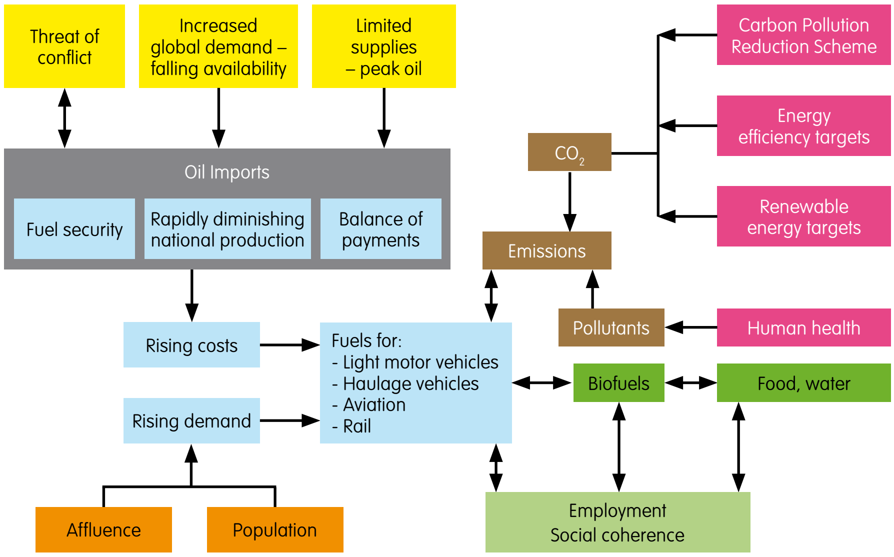
1.1. Growing demand

The issue of future transport fuel supply is exacerbated by increasing demand both for transport fuel and for other products derived from oil (Figure 2).[1] During this century, oil consumption in Australia has increased on an annual basis by an average of 1.5% per annum,[2] and it is estimated that through the decade from 2006/07 demand will grow by 9% (Figure 3). Greenhouse gas emissions associated with this growth have increased from 1990 to 2007 by 27%.[3]

1.2. Climate change

The warming of the Earth is now clearly observed with a range of consequences for aspects of the weather and climate and impacts on natural and human systems.[4,5] Anticipated future consequences for Australia are outlined in CSIRO/Bureau of Meteorology (2007)[6] and Pearman (2008).[7] The warming is connected with a high degree of confidence to the increasing levels of greenhouse gases (mainly carbon dioxide) in the atmosphere. Global and Australian attempts to reduce the levels of future climate change will be built around a revolutionary change in the way energy is sourced and utilized. The transport sector in Australia contributes about 14% of all greenhouse gas emissions at a rate of 79 Mt CO_2e[8] in 2007, and growth of 1.5% annually since 1990.[9]

Figure 1: A summary of the complex range of 'drivers' of future motor vehicle fuel supplies and use.



1 Jamison 2008. *A Roadmap for Alternative Fuels in Australia: Ending our dependence on oil.* Report of the Jamison Group, Diesendorf, M., Lamb, D., Mathews, J. and Pearman, G. Prepared for the NRMA, Sydney, p. 60.

2 Australian Bureau of Agricultural and Resource Economics (ABARE) 2009a. *Energy in Australia, 2009. Petroleum Production and Trade.* http://www.abare.gov.au/interactive/09_auEnergy/htm/chapter_7.htm. p. 16

3 Department of Climate Change 2007. *National Greenhouse Gas Inventory*, 2007. p. 28.

4 Intergovernmental Panel on Climate Change (IPCC) 2007a. *Climate Change 2007. Syntheses Report.* Working Groups I, II and III of the IPCC. Core Writing Team, R. Pachauri and Reisinger, A., IPCC, Geneva, p. 104, or available at http://www.ipcc.ch/ipccreports/ar4-syr.htm.

5 Copenhagen University 2009. *Climate Change: Global Risks, Challenges and Decisions.* Synthesis report from the Climate Congress, March 10-12, Copenhagen. p. 35. http://climatecongress.ku.dk/pdf/synthesisreport.

6 Commonwealth Scientific and Industrial Research Organisation (CSIRO) /Bureau of Meterology 2007. *Climate Change in Australia.* CSIRO and Australian Bureau of Meteorology. Technical Report, ISBN 97819211232930. Available at: www.climatechangeinaustralia.gov.au.

7 Pearman, G.I. 2008. *Climate change: Risk in Australia under alternative emissions futures.* Document prepared as part of the study: Climate Change Impacts and Risk: Modelling of the macroeconomic, sectoral and distributional implications of long-term greenhouse gas emissions reduction in Australia by the Australian Federal Treasury. Available at: http://www.treasury.gov.au/lowpollutionfuture/consultants_report/downloads/Risk_in_Australia_under_alternative_emissions_futures.pdf.

8 All greenhouse gases have a different impact on climate related to their respective molecular structures and lifetimes in the atmosphere. For comparison the impact of greenhouse gases is normally represented by an amount of carbon dioxide that would have an equivalent effect on global warming – CO_2e. In this document, we generally referred only to the effect of carbon dioxide as, for most fuels, the carbon dioxide emissions dominate the impact they have on global warming

9 Department of Climate Change 2007. Above n 3.

With growing global demand, oil prices are anticipated by some to rise steeply through the next decade or two.

Figure 2: History of transport sector energy consumption growth in Australia.[10] Energy is expressed in units of Petajoules (PJ).[11]

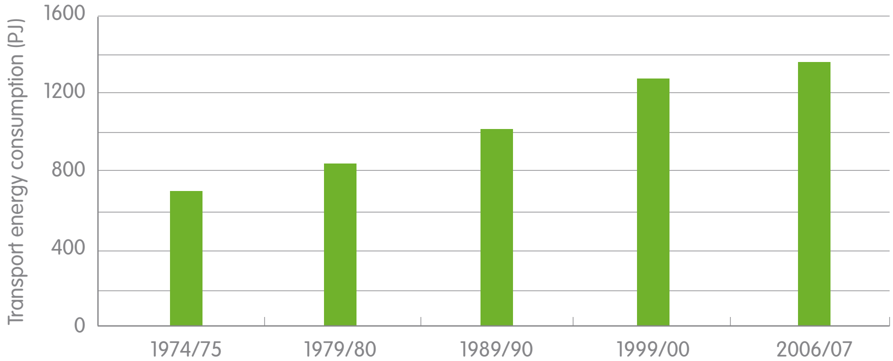
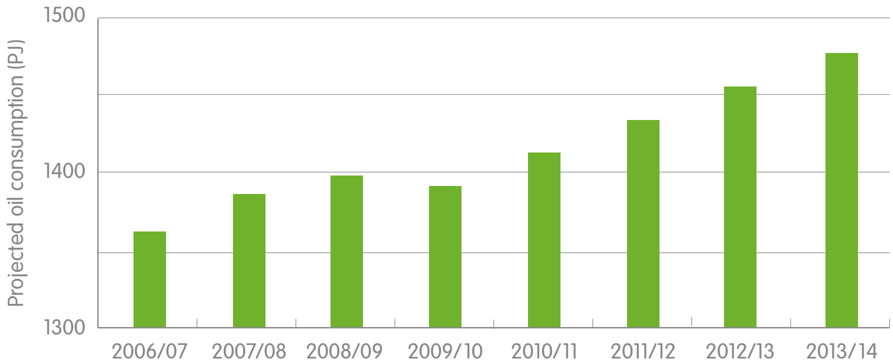


Figure 3: Projected growth of oil consumption in the transport fuel sector in Australia (ABARE 2008, p16).



Such emissions will be under scrutiny as governments and the community seek to reduce emissions voluntarily, through regulation, or through the market impacts of a national carbon trading scheme.

1.3. Peak oil

It is now widely conceded that the global supply of crude oil has reached a stage where new discoveries are generally of smaller fields and exploitable at higher costs than in the past. Some would argue that the supply of oil has now peaked[12] and through the coming decades with diminishing supplies, the price of oil will inevitably rise. In the particular case of Australia this 'peaking' is very clear (see Figure 4). As a result, Australia's domestic capacity to deliver its oil demands reduced from 65% in 1980 to 45% by 2006.

It is anticipated[13] that by 2020 Australia's production of crude oil and condensate would decrease from 2006 levels by a further 56% whilst, based on Bureau of Transport and Regional Economics (BTRE) (2005) figures, demand will grow by a little less than 2% per annum. Thus, using these assumptions in growth our scenario explored in Section 4.5 illustrates by 2020 dependence on imported oil will rise to more than 80% leading to a trade deficit associated with all transport fuels purchased on the global market rising from currently about $10 billion per annum to $15 billion per annum in 2015. This scenario is examined further in Section 4.5 and Table A5.5. These figures could reach $25 billion per annum in 2015 (five years from now) depending on the increase in world oil prices. Table 1 shows the effect of Australia's declining self-sufficiency of petroleum production on trade in recent years.

There are several potential consequences of this outlined in Sections 1.4 to 1.7.

10 ABARE 2008. *Australian Commodities*, March quarter, vol 16, no 1. p. 16.

11 For the benefit of the less technical reader, 1000 PJ per annum is equivalent to energy usage at a rate of approximately 31,000 MW.

12 See Jamison 2008 for discussion. Above n 1 or www.peakoil.org.au.

13 Ibid.

Figure 4: Australian crude oil demand and production.[14]

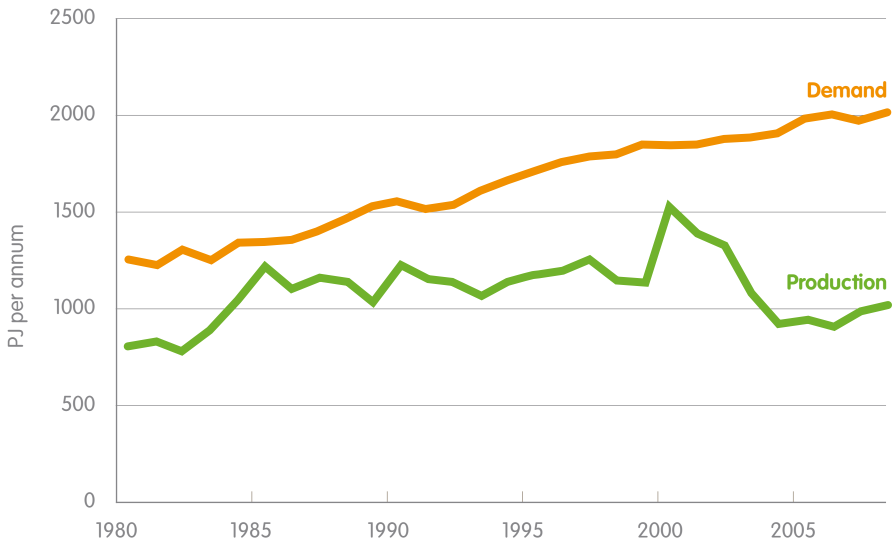


Table 1: Australian trade in petroleum[15]

	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Exports (Aus M$)						
Refined product	1198	918	844	1195	1098	1321
LPG	855	647	804	1002	1038	1182
Bunkers	775	696	951	1322	1295	1457
Crude	6402	5055	6330	6638	8317	10487
LNG	2607	2174	3199	4416	5222	5854
Total	*11837*	*9490*	*12128*	*14573*	*16970*	*20301*
Imports (Aus M$)						
Refined product	2050	3595	5123	8761	8583	13459
Crude	8610	6594	9995	12820	13360	17059
Total	*10660*	*10189*	*15118*	*21581*	*21943*	*30518*
Net	**1177**	**-699**	**-2990**	**-7008**	**-4973**	**-10217**

1.4. Fuel price

With growing global demand, particularly in the newly developing nations, in conditions of diminishing resource, oil prices are anticipated by some to rise steeply through the next decade or two. Others regard prices as potentially falling. This remains a serious unknown in terms of projections of future demand with the risk of dependency on uncertain overseas supplies for a substantial proportion of Australia's transport fleet.

1.5. Balance of trade

The importation of crude oil (excluding refined product) into Australia currently costs the Australian economy $17 billion annually.[16] This is compared to the traded value of exported commodities such as coal, liquefied natural gas, uranium and wheat in Table 2.

The import of crude oil currently all but offsets the total value from the export of coal. This imposition on the balance of trade is likely to grow in the coming years. The dramatic rise in the dollar amount of imported petroleum product from 2006/07 to 2007/08 shows the impact rising oil prices can have on Australia's balance of payments. As the price of crude oil reached US$150/barrel Australia's net imports of petroleum exceeded $10 billion per annum (see Table 1).

14 Modified from Energy Information Administration. Official Energy Statistics from the US Government (EIA) 2009. *Australia – Oil*. Available at: http://www.eia.doe.gov/emeu/cabs/Australia/Oil.html.

15 See ABARE 2009a. Above n 2, p. 29.

16 Australian dollars unless otherwise indicated.

Table 2: Annual export earnings for Australia of major commodities compared with recent (2008-2009) cost of oil imports.[17]

Commodity	Dollar value (BAU$/year)
Export	
Oil	10.0
Coal	18.1
LNG	6.7
Uranium	1.0
Wheat	4.6
Import	
Oil	17.0

1.6. National Fuel Security

Australia's economy is heavily dependent on internal transport capacity and oil-based agriculture. Any threat to the maintenance of these capacities must be seen as a major national security issue. The National Energy Security Assessment[18] defines energy security as adequate, where:

- Adequacy is the provision of sufficient energy to support economic and social activity;
- Reliability is the provision of energy with minimal disruption to supply; and
- Affordability is the provision of energy at a price which does not adversely impact on the competitiveness of the economy and supports continued investment in the energy sector.

It would appear that in this assessment there is a built-in assumption that there will be an endless growth in energy demand and that this demand will be focussed on traditional energy sources. Further, 'affordability' appears to reflect primarily the affordability to industry rather than for individuals, such as in the use of private motor vehicles. There also appears to be no attempt to internalise the environmental and human health costs associated with current energy supply or in the delivery of this trajectory. The climate change issue is not explicitly dealt with other than through the Carbon Pollution Reduction Scheme and its impact on energy price.

The potential for interruptions in energy imports as a result of growing tensions related to the peaking of oil supplies internationally and/or related to political/military actions appears to be glossed over with words such as "the impact of tightening supply/demand balances" and the "need for further market…reforms to…improve the flexibility and resilience of energy markets in the face of disruptions or structural change". The report classifies Australia's liquid fuel security to 2023 as 'moderate'. In a recent article in the UK newspaper *The Independent*, Robert Fisk[19] speaks about a "new world order" with Arab states, China, Russia and France attempting to stop the use of US currency for oil trading and considers some of the potential consequences of this. He concludes such changes could promote further unrest, but from the perspective of this report it may simply drive the US and Australia towards greater independence from oil, with consequences for the emerging automotive technologies. We are not in a position to comment on these ideas, but they illustrate in part the potential risk of change in this domain.

We take a somewhat different view to the National Energy Security Assessment. In the first place the risk associated with a moderate level of security of supply may be interpreted as very high given the potential consequences to the community and economy if disruption was to occur. Risk must be seen as the consequence of both the probability of an occurrence and the magnitude of the impact if it occurred. We believe that the potential for discontinuities in the supply of oil are heightened in a world in which the commodity becomes increasingly competitively sought after, and in a world in which the distribution of resources is geographically and politically divided.

17 ABARE 2009b. *Australian Commodities*, December quarter, 08.4. 15(4). Available at: http://www.abare.gov.au/publications_html/ac/ac_08/ac_08.html.

18 Department of Resources, Energy and Tourism 2009. *National Energy Security Assessment*, Australian Government, Canberra. Available at: http://www.ret.gov.au/energy/Documents/Energy%20Security/National-Energy-Security-Assessment-2009.pdf.

19 Fisk, R. Tuesday 6 October 2009. *The demise of the dollar.* "In a graphic illustration of the new world order, Arab states have launched secret moves with China, Russia and France to stop using the US currency for oil trading". http://www.independent.co.uk/news/business/news/the-demise-of-the-dollar-1798175.html.

It is possible that these levels of cover may not be sufficient to ensure adequacy of supply in domestic markets in the event of a major supply disruption.

Australia's membership of the International Energy Agency provides for access to a 90-day emergency supply in the case of a major disruption. What this does not guarantee is supply in the case of a global disruption during which requests for emergency supplies might be forthcoming from several or many sources. Further, in recent years total stocks of crude oil and products have declined and fallen below the 90-day commitment level in 2006, 2007 and on a monthly basis in the early part of 2008.[20] This raises questions about our national commitment and our security of supply.

Further, these stocks are held by commercial businesses in various forms, such as crude oil at refineries and refinery and marketing terminal stocks of products, "to accommodate short-term fluctuations in demand and are based on commercial considerations" as described in ACIL (2008). The level of each of these reserves is equivalent to between 1 and 15 days of consumption compared to that in the US which is the equivalent of 60 days of national consumption.[21] This heightens Australia's vulnerability despite industry measures such as the diversification of international supply designed to lower vulnerability. Local refineries are required to have enough crude oil and/or product to cater for military requirements, but aside from this, the strategic reserve amounts to what the refineries can store. The ACIL (2008) report concludes that "it is possible that these levels of cover may not be sufficient to ensure adequacy of supply in domestic markets in the event of a major supply disruption" and that "Australia will however need more investment at terminals, … to manage commercial and supply risks identified above; and in order to meet International Energy Agency (IEA) obligations."

Whilst the *Liquid Fuel Emergency Act* [22] provides the mechanism whereby the Government of the day can intervene to manage an emergency due to a shortfall of supply, the consequence of this to Australian society (conduct of business, delivery to schools and places of work, emergency services provision, etc) and the economy are, in our view, demanding of a more inclusive examination of the risks, the public communication of those risks, and the development of more inclusive strategies.

1.7. Air quality and human health

Motor vehicle emissions of particulates and the chemical precursors of photochemical smog, nitrogen oxides and volatile organic compounds contribute to human health problems and morbidity, particularly in cities. The Bureau of Transport and Regional Economics (BTRE)[23] concluded that in the year 2000, motor vehicle-related air pollution accounted for between 900 and 4500 morbidity cases (cardiovascular and respiratory diseases and bronchitis) and between 900 and 2,000 early deaths. The economic cost of air-pollution-related morbidity was estimated to range from $0.4 billion to $1.2 billion per annum and for early deaths, $1.1 billion and $2.6 billion per annum.

The significance of the impact of vehicle emissions' on community health and morbidity is highlighted when compared to road death statistics with an average of over 1,500 people dying on Australian roads each year for the past five years.[24] Vehicle emissions are contributing to a similar, if not more significant, impact on our community.

The BTRE study was constrained by the lack of solid observational data on small particles and having to use particle concentration-health risk estimates based on levels of particles that were up to 10 microns (μm) in diameter. There is a deficiency in knowledge of the relative role of smaller particles, (less than 0.2 μm), on health, as these are more likely to penetrate deep into respiratory systems. These are likely to be reduced in emissions of modern petrol vehicles with reduced fuel consumption, but there remains uncertainty as to the efficacy in this regard of particle filter systems designed to remove the larger particles in diesel exhaust.

20 ACIL Tasman 2008. *An Assessment of Australia's Liquid Fuel Vulnerability*. Report prepared for Department of Resources, Energy and Tourism. p. x, xxii. http://www.ret.gov.au/energy/efficiency/eeo/pages/default.aspx.

21 Wilson, N. 2004. 'Australia - Plan to protect oil supply' *Energy Bulletin*, 20 August 2004. Available at: http://www.energybulletin.net/node/1691.

22 Liquid Fuel Emergency Act 1984, Canberra. Available at: http://www.austlii.edu.au/au/legis/cth/consol_act/lfea1984213/

23 BTRE 2005a. *Health Impacts of Transport Emissions in Australia: Economic Costs*. Working Paper 63. Australian Government Department of Transport and Regional Services, p. 147. BTRE is now nown as the Bureau of Infrastucture, Transport and Regional Economics (BITRE).

24 BITRE, 2009. *Road Deaths Australia*, November 2009. Australian Government Department of Infrastructure, Transport and Regional Economics. p. 8.

2. A holistic approach

It is folly to think that Australia's transport energy needs can be met with a single solution. The role of transport, now and in the future, is complex and multi-faceted. As such, only a holistic approach to the challenges of fuel supply will suffice, one that recognises economic imperatives, the realities of infrastructure development and the demands of the populace.

We must seek options that identify suitable transitions from where we are to desirable futures.

Given multiple dimensions of current and future transport fuels, it is appropriate for an organisation such as NRMA, representing over two million Australian motorists, to ask the Jamison Group to examine on their behalf questions about strategic directions that should be taken to ensure continuity of transport options. The position taken in this paper is that it is impossible to properly assess these circumstances without taking a holistic approach. That is: one in which as many dimensions of the role of transport within modern and future communities is considered together with the factors identified above; and, one in which fuel options cannot be separated entirely from technological change and governance intervention. A similar approach was taken by CSIRO/RIRDC.[25]

Transport exists as a major part of the Australian way of life. It provides individuals with access to workplace, to the conduct of business and trade, to education, to participation in community and social activities, to tourism and recreation. Yet, this transport demands simultaneous consideration of:

- The design of cities, their liveability, and environmental protection;
- Delivery of economic benefits, food production, retailing, tourism, manufacturing and commerce;
- The interface between urban and regional Australia;
- Alternative modes of transport, public and private: trains, buses, trams, aircraft, bicycles, walking; and the balance and interactions between them;
- Infrastructure provision, roads, bridges, fuel distribution;
- Regulation, safety and policing;
- Impacts on the balance of trade and national security; and
- Opportunities or dependency on existing and emerging technologies for future automotive design, manufacture and motoring options.

These are difficult issues to address singularly, let alone holistically. We attempt here to commence this process, in the belief that strategies need to be cognisant of the range of potential outcomes of decisions that focus on delivering motor vehicle fuel options for the future. Decisions made with a holistic–approach are, in our view, more likely to avoid narrow systems approaches that can be so focussed as to lose the capacity to respond to unforeseen change, be captured by preconceived sectoral interests, produce perverse and unanticipated outcomes and, given the complexity and limitation of knowledge at any point of time, reflect the fact that perfect anticipation of outcomes for any approach is not possible.

Finally, we attempt to seek options that reflect the current realities and identify suitable transitions from where we are to desirable futures. We do this by examining the range of fuel options (summarised in Table 3 and discussed in Section 3 below) and then by producing a notional portfolio of responses as one view of how the future of motor fuels and vehicles may unfold (see Section 4).

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25 CSIRO/Rural Industries Research and Development Corporation (RIRDC), 2007b. *Biofuels in Australia – An Overview of Issues and Prospects*. CSIRO report to the Australian Government Department of Rural Industries Research and Development Corporation, Canberra, p. 20. Available at: https://rirdc.infoservices.com.au/downloads/07-070.pdf.

Table 3a: A summary of the options, pros and cons, for the provision of **diesel fuels** for automotive operations in Australia. For glossary and acronyms, see Table 3d on page 31.

Diesel						
Feed-stock	**Process**	**Potential contribution to energy demand**	**Potential contribution to greenhouse gas (GHG) emissions reduction**	**Technology readiness**	**Technology costs**	**Horizon**
Coal	Direct liquefaction	Large. Coal reserves in Australia are very large equivalent to approximately 5 times those of natural gas and 15 times oil reserves and under-utilised (domestically or for export)	This technology is not mature; without CCS would increase Australia's GHG emissions by 2-3 times compared to diesel refined from oil. CCS technologies are being researched in Australia and globally; there are some pilot-scale demonstration facilities in operation. However, large-scale CCS would need to be practised in order for CTL technologies to have a neutral or beneficial impact on GHG emissions	Direct liquefaction CTL technologies are at demonstration scale with no commercial facility available. CCS technologies, which are essential to the environmental viability of CTL technologies are at pilot scale testing. It is not anticipated that this technology will contribute significantly to Australia's energy demands for at least 10-15 years	Unknown	Long
	Gasification / FTS		Without CCS would increase Australia's GHG emissions by 2-3 times compared to diesel fuel refined from oil. More energy efficient gasification and FTS technologies are being researched but CCS would still be required to ensure no net increase in GHG emissions came from using this CTL technology	Several small operations around world. Currently China is in negotiations with a leading South African company to build two plants with a capacity of approximately 1 million barrels of oil a day each (2500 PJ/annum each). Existing CTL plants produce in the order of 50 PJ	Cost prohibitive in a carbon constrained economy without CCS	Medium
Natural Gas	Direct processes	Moderate	Unknown but not expected to be significantly better than diesel fuel refined from oil. GHG emissions would be technology dependent	Lab and demonstration scale projects are currently underway. Commercial operations a minimum of 10-15 years away.	Unknown but not expected to be competitive with oil based on current oil prices	Long
	Via syngas /FTS	Small. Up to 20% long term but not expected to be more than 10% in the next two decades. The natural gas feedstock is plentiful in Australia (>80000 PJ or >20 years supply at current usage rates and with no future discoveries). Competition for gas from electricity generation, industrial use and exports	About on par with oil-derived diesel with current technologies. It is anticipated that process improvements would see energy demands and consequent GHG emissions reduce over time. The process improvement statement can be said of most of the technologies in this Table	Two commercial-scale operations. Experience to be made from operation of existing plants in the same way it was in LNG production once commercial facilities were established	Currently more expensive than diesel from oil. Economics expected to improve as number of plants increase. Capital costs higher than oil refining. Large-scale commercial competitiveness depends on availability of cheap gas (approx. $5/GJ long term) and oil prices of in excess of $100 a barrel based on current technologies. Capital costs will also change with changing energy prices	Medium
Biomass	Extraction and upgrade of plant oils	Small. Up to 10% in the medium term.	Small. The disperse nature of the biomass feedstock means that GHG emissions from transport might weigh against biomass-derived fuels unless decentralised processing was practised and local uses for the fuels could be found. Potential issues around displacement of farming land	Several small operations around world making blendstocks for larger refining facilities or with local distribution networks (e.g. farms)	Currently require subsidies but could have significantly improved economics in a carbon constrained economy	Short to medium
	Microbe-based systems	Moderate	Moderate. High solar-efficiency microbe-based systems could play a significant part in reducing GHGs from transport fuel production. As with the above point local supply chains would improve the case for GHG reduction using this technology	Lab and demonstration scale	Unknown	Medium
	Gasification / FTS	Small. Up to 10% in the medium term	Small-based scale. Issues around displacement of farming land and GHG costs to transport biomass to site of processing. An advantage of this technology is its lack of feedstock discrimination (i.e. it can use any biological feedstock that can be burned including crop and farming wastes. Could be issues around removal of soil nutrients if crop wastes are used in this way where they otherwise might be used in the farming process	Technical scale and larger. Commercial facilities have operated in the past	High compared to oil refining at current prices. However could have significantly improved economics in a carbon-constrained economy	Medium

Table 3b: A summary of the options, pros and cons, for the provision of **petrol/gasoline and LPG** for automotive operations in Australia. For glossary and acronyms, see Table 3d on page 31.

Feed-stock	Process	Potential contribution to energy demand	Potential contribution to GHG reduction	Technology readiness	Technology costs	Horizon
Petrol/Gasoline						
Coal	Direct liquefaction	Large. Coal reserves in Australia are very large and much of these are not utilised (domestically or for export). Australia has reserves of coal equivalent to approximately 5 times those of natural gas and 15 times oil reserves	This technology is not mature and without CCS would increase Australia's GHG emissions by 2-3 times compared to petrol refined from oil	Laboratory scale / Technical feasibility	Unknown	Long
	Gasification / FTS		Without CCS would increase Australia's GHG emissions by 2-3 times compared to petrol refined from oil	Pilot scale	Cost prohibitive in a carbon-constrained economy without CCS Not competitive with oil at current oil prices Added capital cost for CCS unit	Medium without CCS; longer with CCS
Natural Gas	Via syngas / methanol	Moderate. There are large natural gas reserves in Australia but gasoline from natural gas also competes with diesel from natural gas, LNG and CNG as well as gas for household purposes, electricity and industrial use, and exports	About on par with oil-derived fuels with current technologies so contribution would be negligible with current technologies	Small-scale commercial operations	Would require subsidy and would probably devalue the intermediate product (methanol). Would require high oil prices and low gas prices to be competitive with alternatives such as oil-derived fuels and LNG	Long
Biomass	Gasification / methanol	Small. Up to 10% in the medium term.	Small-based scale. Issues around displacement of farming land and GHG costs to transport biomass to site of processing. An advantage of this technology is its lack of feedstock discrimination (i.e. it can use any biological feedstock that can be burned, including crop and farming wastes. Could be issues around removal of soil nutrients if crop wastes are used in this way where they otherwise might be used in the farming process	Lab scale / Technical feasibility	High compared to oil refining at current prices. However could have significantly improved economics in a carbon-constrained economy	Medium
	Microbe-based systems (fermentation)	Moderate	Moderate. High solar-efficiency microbe-based systems could play a significant part in reducing GHGs from transport fuel production. As with the above point local supply chains would improve the case for GHG reduction using this technology	Lab and demonstration scale	Unknown	Medium
Liquefied Petroleum Gas (LPG)						
Natural Gas	Separation / concentration / compression	Small (up to 10% of transport fuel requirements). There are large reserves of natural gas in Australia, some of which are currently producing LPG as a bi-product of LNG production	Could make a small contribution to reducing GHGs using current technologies without CCS Much more significant with CCS	Commercially available Infrastructure in existence	On par or cheaper than oil with current subsidies	Immediate

Table 3c: A summary of the options, pros and cons, for the provision of **further fuel types** for automotive operations in Australia. For glossary and acronyms, see Table 3d page opposite. The role of electricity is discussed in the Jamison *The Electric Vehicles Revolution* 2010.

Feed-stock	Process	Potential contribution to energy demand	Potential contribution to GHG reduction	Technology readiness	Technology costs	Horizon
Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG)						
Natural Gas	Compression (CNG)/ liquefaction and regasification (LNG)	Large, but transport uses are subject to competition from electricity generation, industrial uses and export	Could make a small contribution to reducing GHGs using current technologies without CCS for use as a transport fuel. For use in electricity generation and ultimately for use in electric vehicles there could be significant GHG savings that would be much more significant with CCS	Commercially available. Infrastructure requires some modification for use as a fuel. Gas-fired power plants would need to be built for use in electricity generation	On par or cheaper than oil	Medium
Ethanol						
Biomass	Fermentation	Small. Up to 10% in the medium term. Would most likely be used as a gasoline blendstock. Possibly 100% for rural use	Moderate depending on technologies used. Issues around displacement of farming land and GHG costs to transport biomass to site of processing. Issues also around type of biomass used	Well-established commercial process in first generation. Second generation under development	With no CCS incentive would require small subsidy to be competitive	Medium
Methanol						
Biomass	Fermentation	Small. Could be used as a gasoline blendstock	Moderate depending on technologies used. Issues around displacement of farming land and GHG costs to transport biomass to site of processing. Issues also around type of biomass used	Commercial process	Would require subsidy and would probably devalue the product (methanol) for chemical applications	Medium
	Microbe-based systems	Small	Moderate	Proof of concept	Unknown	
	Via syngas	Medium to large	Medium to large, subject to issues around possible displacement of farming land	Commercial process	Would require subsidy	Medium
Natural Gas	Via syngas	Small. Other natural gas to fuels options would be favoured over methanol production	Up to 20% over existing fuel production from oil. Overall, GHG reduction would be small due to the anticipated small contribution to energy demand	Several commercial operations for making chemicals and chemical intermediates	Would require subsidy and would probably devalue the product (methanol) for chemical applications	Medium
Dimethyl ether	Via syngas / methanol	Small. Other natural gas to fuels options would be favoured over DME production	Moderate. Up to 20% over existing fuel production from oil. Overall, GHG reduction would be small due to the anticipated small contribution to energy demand	Small-scale commercial operations	Other uses for DME, such as household use, would compete for DME. However with large enough production of DME economics would improve and it could exist as a transport fuel in its own right	Medium

It is impossible to properly assess circumstances without taking a holistic approach.

Table 3d: Definitions and key to acronyms used in Table 3a-c.

Alternative fuel	Process	Potential contribution to energy demand	Potential contribution to GHG reduction	Technology readiness	Horizon
DME: Dimethyl ether	**Syngas:** Gaseous mixture of hydrogen and carbon monoxide. Intermediate for production of a range of fuels and chemicals	**Small:** Less than 10% of future energy demand	**Negligible:** Approximately the same as existing technologies	**Lab scale/ proof of concept:** Earliest research phase. In terms of barrels of oil per day equivalent this would be <1 BOE/day	**Long:** Greater than 20 years
LNG: Liquefied Natural Gas	**Direct Liquefaction:** Process that does not involve production of syngas	**Moderate:** Between 10 and 20% of future energy demand	**Small:** About 10% reduction over existing technologies	**Demonstration scale:** Scale larger than lab scale (BOE: 10)	**Medium:** Between 10 and 20 years
LPG: Liquefied Petroleum Gas	**Gasification:** A means of producing syngas from coal or biomass	**Large:** Greater than 20% of future energy demand	**Moderate:** Between 10 and 20% over existing technologies	**Pilot scale:** Scale larger than demonstration scale (BOE: 100)	**Short:** Less than 10 years
CNG: Compressed Natural Gas	**Fermentation:** Microbial-based process for converting starches in biomass to alcohols		**Increase:** An increase compared to existing technologies	**Technical scale:** Scale larger than pilot scale and smaller than commercial scale (BOE: 1000)	
Petrol	**FTS:** Fischer Tropsch Synthesis. Chemical process for turning syngas into fuels			**Commercial scale:** Large scale supplying product to market (BOE: 10000+)	

3. Options for alternative fuels

Significant progress has been made in the use of electricity to power motor vehicles and trends show that electric vehicles should soon make up a significant component of Australia's fleet transport. The electrification of motive systems is one part of a plan to make greater use of alternative fuels, one that will utilise gas and biofuels to extend oil use and provide a transitional energy supply.

Electricity is a viable fuel for transport, particularly for the majority of vehicles that are required to perform frequent short-journey trips.

In considering options for alternative fuels for Australia's light motor vehicle fleet, it is necessary to simultaneously recognise the range of current and unfolding technological options, the existing investment in those technologies and refining and distribution systems, the rate at which change can be, or needs to be, instigated and the economic and social barriers to change. We first summarise the potential for the electrification of motor cars in Australian (dealt with in more detail in Jamison *The Electric Vehicle Revolution* 2010);[26] second we consider the role of gas in its several forms and sources as well as briefly touching on oil-based fuels; and third, we consider the potential for the use of biomass for the production of fuels for cars with internal combustion systems. We examine for each of these key options, what is the current situation and what are the key issues (technologies, infrastructure, gross capacity, costs, etc).

3.1. Electricity

Jamison (2008)[27] concluded that the most likely strategic development in motor vehicle technologies over the next several decades will be the electrification of the motive systems. Since that report, developments in this regard have been very rapid. For this reason, we have prepared an analysis of these developments separately in Jamison *The Electric Vehicle Revolution* 2010 and summarise the main outcomes of that study here.[28]

There are a number of factors to be considered in this transition such as the relative role of hybridisation of the motive systems over time, the on-board storage of energy and the sourcing and distribution of the energy. These and other factors are covered in the companion report. In summary, this concludes that electricity is a viable fuel for transport, particularly for the majority of vehicles that are required to perform frequent short-journey trips. Electric cars will be available for Australian car buyers from 2012 and are likely to be adopted quickly within cities.

The absence of exhaust pipe emissions offers cleaner air quality in cities, especially in congested zones where electric vehicles perform best. As electric-vehicle penetration increases, so does the opportunity for energy storage in their batteries to increase the contributions of intermittent power sources such as wind and solar energy. An issue that requires planning and management is that of controlling the displaced emissions to the power generating stations, with a strong preference that electric vehicles be powered only from renewable energy sources. In the notional portfolio for motor cars considered below, we have projected a 5% reduction of imported fuel demand due to the uptake of electric car technologies by 2020, with a strong growth in electric-car use thereafter contributing to a 12% reduction in energy demand from liquid fuels by 2030.

26 Jamison Group 2010. *The Electric Vehicles Revolution*. Report of Jamison Group to NRMA.

27 See Jamison Group 2008. Above n 1.

28 Jamison 2010. Above n 26.

Figure 5: Pathways for the conversion of crude energy supplies into fuels for transport.

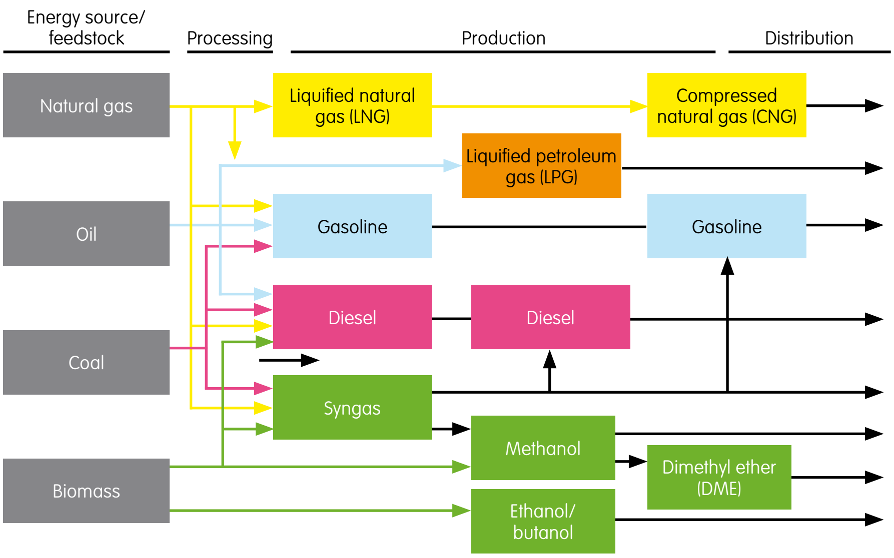
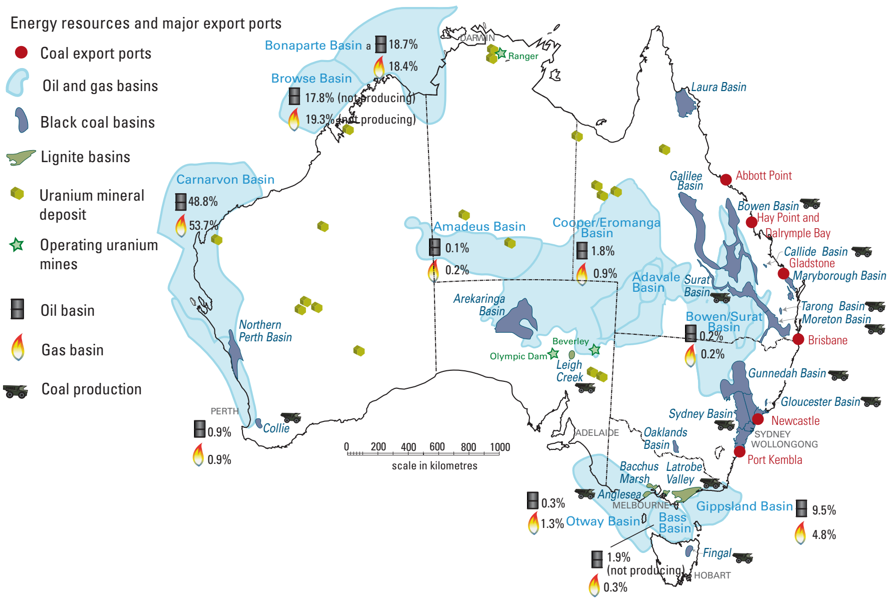


Figure 6: Oil, coal, gas and uranium resources in Australia.[29] Resources are shown as a percentage of total demonstrated resources at 1 January 2010.



Source: Energy in Australia 2009. The Australian Bureau of Agricultural and Resource Economics (ABARE) is an independent economic research agency of the Australian Government.

3.2. Alternative liquid transport fuels – summary of options

Potentially, energy for motor vehicles may be derived from one of a number of the primary energy resources of natural gas, oil, coal or biomass. Each of these resources may be transformed through processing into gaseous or liquid fuels of sufficient energy density to be useful as a current or future fuel option (see Figure 5). The distribution and size of Australian fossil resources is shown in Figure 6, including oil, gas, coal and uranium. As such, however, each fuel option variously involves costs and greenhouse gas emissions that in turn need to be considered in assessing the real value of the alternative into the future. We will examine each option in this Section (further detail is provided in Appendices 1 and 2 and summarised in Table 3 above) and discuss potential contributions to Australia's liquid fuel requirements and reduction of greenhouse gas emissions over the next two decades.

3.2.1. Gasoline and diesel from oil

The majority of Australia's transport fleet is fuelled by gasoline and diesel. For most of the world these fuels are produced by the refining of crude oil. Of the 15.3 million vehicles registered in Australia in March 2009, 13.0 million were gasoline vehicles and 1.83 million were diesel vehicles (Figure 7).[30] The remaining 0.47 million registered vehicles were dual fuel or gas (LPG/CNG) fuelled. Of the 15.3 million vehicles, 11.8 million were passenger vehicles.

29 See ABARE 2009a. Above n 2.

30 Australian Bureau of Statistics (ABS) 2009. Motor Vehicle Census, Australia, 31 Mar 2009. Available at: http://www.abs.gov.au/ausstats/abs@.nsf/PrimaryMainFeatures/9309.0?OpenDocument.

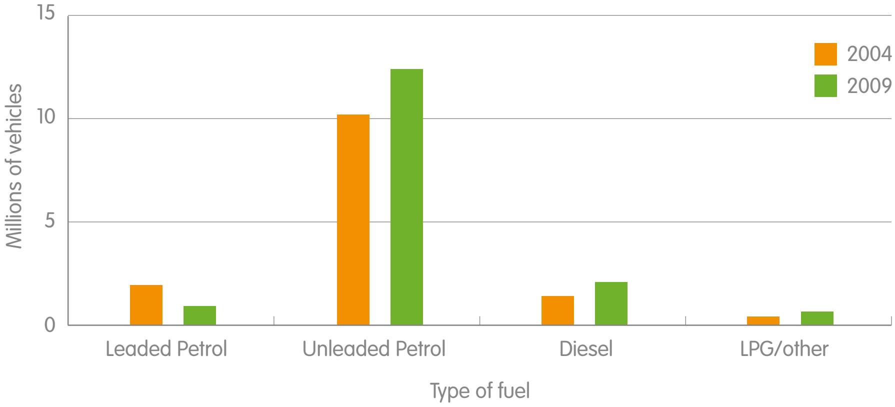
Local crude oil supplies are diminishing and Australia is increasingly reliant on imported crude or refined product to meet its demand for these fuels.

These figures show the dependence of Australia's transport sector on crude oil for transport fuel. As discussed earlier, local crude oil supplies are diminishing and Australia is increasingly reliant on imported crude or refined product to meet its demand for these fuels. Currently Australia meets about 45% of its transport fuel requirements through indigenous oil production and condensates.[31] This figure has declined in the last decade and now imposes a gross import burden in excess of $30 billion per annum on the Australian economy (see Table 1). The reasons for this decline in transport fuel self-sufficiency are twofold: local oil production has decreased in this time and demand for transport fuel has increased.

Based on 2007 figures, Australia has enough reserves of oil for just over four years of consumption at the current rate of around 900,000 barrels per day or approximately 52 GL per year.[32] Including resources that are currently uncommercial (not producing), local demand could be supplied from known local oil resources for around 16 years assuming no increase in per annum consumption.

Given these figures there is a strong case for looking at alternatives to oil for transport fuel supply, from both security of supply and energy self-sufficiency standpoints. There is also the driver for decreasing our dependence on crude oil of minimising climate change impacts.

Figure 7: Motor vehicle fleet in Australia by fuel type.[33]



31 Australian Petroleum Production and Exploration Association. (APPEA) 2008. Key Statistics 2008. Canberra. p. 10. Available at: http://www.appea.com.au/content/pdfs_docs_xls/Statistics/key_stats_2008_6.pdf.

32 See ABARE 2008 above n 10.

33 Based on ABS 2009. Above n 30.

In the short term, natural gas could be a medium-term solution to offsetting Australia's dependence on imported oil.

3.2.2. Transport fuels from natural gas and coal

Natural gas, coal and biomass can all be converted to gasoline and diesel via various chemical conversions (see Figure 8). Fuels produced by these methods can be used in internal combustion engines or can be used as refinery blendstocks. Australia's total natural gas reserves are quoted as 81,437 PJ.[34] This is equivalent to approximately 20 years supply assuming production at current rates (natural gas: 1,950 PJ per annum for non-transport use and straight replacement of oil based transport fuels for gas-derived fuels and no further discoveries).[35] Such a hypothetical scenario, where all oil fuels are replaced immediately by natural gas, cannot happen, but it exemplifies the point that local gas reserves are more plentiful than oil reserves and with the right infrastructure investments in the short term, natural gas could be a medium-term solution to offsetting Australia's dependence on imported oil. Australia has much larger reserves of coal than natural gas and these too can be converted into transport fuels. The next sections will summarise the options for transport fuels from natural gas and coal. Appendix 1 considers the infrastructure requirements and emissions consequences of substituting oil with natural gas as our transport fuels feedstock.

3.2.2.1. Liquefied petroleum gas

Liquefied petroleum gas (LPG) is a by-product of the oil refining process as well as a side product of liquefied natural gas (LNG) production; approximately 80%[36] of LPG in Australia comes from LNG. The remainder comes as a by-product of the oil refining process. Australia has an extensive LPG distribution network and government rebates for conversion of gasoline-fuelled vehicles to LPG or a combination of gasoline and LPG. As Australia's oil reserves decline, a greater percentage of LPG will come from gas production rather than oil production so an increase in demand for LPG and other natural gas-derived fuels will offer producers an increased market size but could also lead to increasing gas prices. Currently, LPG-fuelled vehicles are cheaper to run on a per kilometre basis than gasoline-fuelled vehicles. LPG is currently not taxed by the Federal Government. Over the next 5-6 years excises will be introduced in steps to LPG sales. This will increase the price of the fuel and might also influence the rate of uptake of LPG vehicles.

Unlike liquid-fuelled vehicles, LPG vehicles require pressurised tanks to store the fuel and LPG-fuelled vehicles generally have a shorter range than gasoline or diesel-fuelled vehicles. Higher-capacity and higher-pressure tanks for LNG and CNG vehicles are being researched so that the range issue with gas-fuelled vehicles might be better addressed.

Natural gas storage tanks are larger than petrol fuel tanks for the same range and this is an issue for car designers. However, for buses and trucks it is not so much of an issue. Line-haul trucking companies are taking advantage of the lower operating cost opportunities offered by natural gas.

Moderate capital outlay for the plant to liquefy gas drawn from city pipeline supplies results in early pay-back for companies operating fleets of point-to-point line-haul heavy transport.

34 EnergyQuest, 'Energy Quarterly Report,' *Energy in Australia*, August 2009, p. 26, 31.

35 Ibid, p. 68.

36 http://www.lpgautogas.com.au/index.cfm?Action=About. and go to About LPG Autogas.

Australia has vast quantities of natural gas but a depot-based distribution network such as those existing for gasoline, diesel and LPG does not exist.

Should the proposed target of 10% of the vehicle fleet being LPG vehicles in the next decade be attained, that is an increase from the current position of around 8%, this could reduce the demand for oil by around 50 PJ per annum, a saving of approximately 7% over business as usual (see Section 4 – Potential fuel options/scenarios – for more details).

Savings of greenhouse gas emissions by replacing oil-derived fuels with LPG are harder to quantify.[37] It is not anticipated that use of LPG would have a significant impact on reducing these emissions compared to oil-based fuels; however tailpipe particulate and toxic emissions (CO, unburned fuels) would be reduced.

3.2.2.2. Liquefied natural gas (LNG) and Compressed natural gas (CNG)

Australia produces large quantities of natural gas (1950 PJ per annum)[38] and has large reserves (81437 PJ – see above). Natural gas in the form of CNG can be used to fuel vehicles. LNG could also be used to fuel vehicles once re-gasified. In many respects natural gas is similar to LPG. The fuel is stored in high-pressure tanks and is gaseous at ambient temperature and pressure, and vehicles that use these fuels have a shorter range than gasoline or diesel vehicles.

Australia has vast quantities of natural gas (see Figure 6 above). However a depot-based distribution network such as those existing for gasoline, diesel and LPG does not exist for natural gas. Natural gas is supplied domestically in many parts of Australia and, in theory, refilling of CNG vehicles could be performed at home. Some modifications of the domestic natural gas supply infrastructure, such as increasing delivery pressure of the supply system would be required in order to deliver the gas at sufficient pressure.

In the scenario where fuelling of gas vehicles occurs from home, compressors would be required to ensure that vehicle storage tanks could be charged with enough gas to allow sufficient vehicle range. CNG vehicles have shorter ranges than LPG, diesel and gasoline vehicles. Consequently, larger or higher pressure on-board storage tanks or more frequent refills are required. This has been something of a stumbling block for CNG vehicles, particularly in the absence of a CNG refuelling infrastructure. Currently, CNG is used mainly in depot-based bus fleets and point-to-point haulage trucks in Australia. There will be in excess of 1200 buses running on natural gas in capital cities around the country by 2011.[39] Buses and trucks can carry larger tanks than passenger vehicles and when operated in a return-to-base mode have no need of CNG distribution networks. CNG could also be used to fuel taxis as an alternative to LPG.

Minor fuel system modifications are required for natural gas to be used in petrol or diesel vehicles. This would not be a major task as viability of the equipment and procedures involved in operating numbers of diesel vehicles on natural gas has been proven in the Australian Direct Injection Natural Gas Demonstration Project from October 2007 though March 2008. The project was supported with funding from the Australian Government through the Australian Greenhouse Office and involved three major trucking operators in Perth and Melbourne. Loads of between 30 and 100 tonnes over distances between 300 km and 800 km and a variety of commodities such as crude oil, refrigerated goods and milk products were trialled. Sufficient numbers of passenger vehicles are in operation overseas to obviate any need for further testing of the technologies in Australia.

There are existing markets for natural gas (LNG and domestic gas mostly) so CNG vehicles would likely compete with these demands on the resource. This is not seen as an immediate problem in terms of supply of natural gas for use in vehicles as there is ample natural gas and there have been several reserves discovered in recent years (see Appendix 2).

There are very few natural gas vehicles in Australia at present. An increase in numbers of natural gas fuelled vehicles equivalent to the expected rise in demand for oil-based fuels would reduce the growth in demand for oil in this country.

The reduction of greenhouse gas emissions by the use of natural gas vehicles in place of petrol or diesel vehicles would be modest, as discussed in Appendix 1.

The use of fugitive emissions of natural gas (that is, gas that currently escapes or is wasted in the production processes such as in coal seam gas emissions) would have a significant impact in reducing greenhouse gas emissions in that these fugitive emissions, normally associated with mining and drilling operations could be captured and stored for use in vehicles, thus reducing the impact of these emissions by a factor of approximately 24.

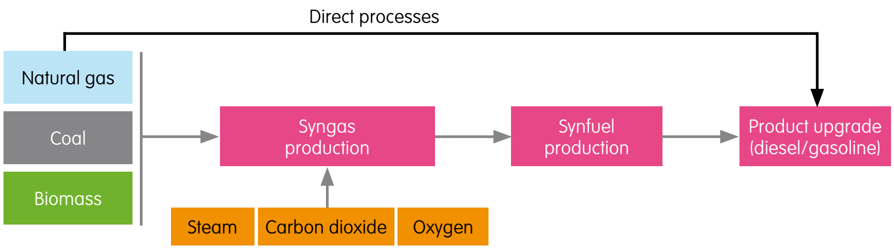
37 Kalnes, T. N., Koers, K. P., Marker, T., and Shonnard, D. 2009. 'A technoeconomic and environmental life cycle comparison of green diesel to biodiesel and syndiesel.' *Environ. Progress and Sustainable Energy* 28(1), 111-120.

38 See EnergyQuest, above n 34, p. 68.

39 www.Envirofuel.com.au/2007/06/13/natural-gas-buses/

GTL fuels also have the advantage of producing a cleaner burning product and a range of valuable by-products such as high-grade lubricating oils.

Figure 8: Steps in the production of transport fuels from non-oil feedstocks.



3.2.2.3. Gas-to-liquid (GTL) conversion

As well as being compressed and used directly as a fuel, natural gas can be converted into other transport fuels such as diesel, gasoline and methanol. The processes for converting natural gas to gasoline, diesel and other transport fuels are known as gas-to-liquids (GTL) transformation. No commercial GTL plants exist in Australia at present but there are several plants around the world. GTL products can be sold directly into the distribution network or blended with refinery feedstock. The cost of producing liquid fuels from natural gas depends on many factors such as the price of the gas used, the price of competing fuel production technologies (crude oil refining, coal-to-liquids technologies, others) and the cost of emissions in a carbon-constrained environment.[40] Figure 8 shows the process of transforming natural gas, coal and biomass into liquid transport fuels.

GTL fuels also have the advantage of producing a cleaner burning product and a range of valuable by-products such as very high-grade lubricating oils. GTL products require little or no engine modification. In comparison to crude oil, natural gas generally contains fewer impurities such as sulphur.[41]

A benefit of the cleaner fuel produced from natural gas is the ability to use it as a blendstock. That is, the cleaner fuel can be mixed with its oil-derived equivalent in order to meet more stringent fuel standards. This approach could be particularly appealing in Australia's case where aging refineries could continue production without the need of capital investment to upgrade facilities and still be able to deliver fuels that meet fuel quality requirements.

There is a variety of fuels that can be produced from natural gas including gasoline, diesel, methanol and dimethyl ether (DME). The processes used industrially involve converting natural gas to synthesis gas (syngas – a mixture of carbon monoxide and hydrogen), then combining these molecules to make the desired fuel (see Figures 5 and 8). In the case of DME production and methanol-to-gasoline production a third step is required. There are also novel (as yet non-commercial) techniques for conversion of natural gas to liquids.

Each of the commercial processes will be discussed briefly here. A more detailed discussion of these fuels can be found in Appendix 1.

Methanol

Production of methanol from natural gas is currently the main means of methanol production globally. In excess of 80,000 tonnes per day of methanol is produced from coal and natural gas feedstocks worldwide (approximately 660 PJ per annum based on energy content of methanol of 22.7 MJ/kg).[42] The technology

40 Jaramillo, P., Griffin, W., and Matthews, H. 2008. 'Comparative analysis of the production costs and life-cycle GHG emissions of FT liquid fuels from coal and natural gas.' Environ. *Sci. and Technol.* 42(20): 7559-7565.

41 Maly, R. 2004. 'Effect of GTL diesel fuels on Emissions and Engine Performance.' *10th Diesel Engine Emissions Reduction Conference*, August 29 – September 2, 2004, Coronado, California.

42 Lide, D. R. 2008. *CRC Handbook of Chemistry and Physics*, 89th Edition, Taylor & Francis.

for the production of methanol is mature and very large-scale plants such as the Atlas facility in Trinidad, which produces approximately 7,000 tonnes per day of methanol (approximately 5.8 PJ per annum), are now in operation and, while smaller, are comparable in size to oil refineries and LNG facilities. Methanol is made predominantly as a feedstock for the chemical industry but can be used as a fuel additive or can be converted into gasoline or DME. It is used directly as a fuel in some racing cars.

Dimethyl ether (DME)

DME production in China has grown appreciably in the last decade with most of the production from coal.[43] China's production of DME is approximately 4.6 Mt per annum (126 PJ per annum). DME can be used as a transport fuel as is, or blended, but is normally used for household purposes.

While the increase in scale of production of methanol and DME has been impressive in recent times, the total production of these fuels remains low compared to the worldwide liquid fuel production. Total liquid fuel consumption in 2008 was 85.5 million barrels per day (183,000 PJ per annum). Methanol and DME production amounted to approximately 0.5% of the total.[44] It would be possible for DME and methanol to play a greater role in transport fuels in Australia, but for this to occur, significant investment in production equipment would be required. For 10% of Australia's transport fuels requirements (in current terms) to be supplied by DME/methanol a facility approximately the size of a medium-sized oil refinery would be required and supply of natural gas would have to be guaranteed for at least 20 years to ensure recovery of capital outlay. Some engine modification would be required unless DME/methanol was used as a blendstock in low concentrations. The blendstock option would be the easiest to handle from an infrastructure perspective.

The contribution these fuels could make to reducing greenhouse gas emissions is dependent on several factors the most important of which are the type and location of the feedstock (coal or natural gas), the availability of carbon capture and storage facilities, and the technology used in the syngas generation stage of the process. With the correct technology and feedstock choices a reduction of up to 20% compared to oil-derived fuels of similar energy content could be made. Methanol can also be produced from biomass with potentially low greenhouse gas emissions (see below).

DME and methanol derived from natural gas and burned in internal combustion engines yield lower tailpipe emissions of unburnt fuels and toxic gases.

Methanol to gasoline

As well as being used as a fuel in its own right, methanol can be converted into gasoline (see Figure 5). Gasoline produced in this way can be used as a straight replacement for gasoline refined from crude oil (i.e. there are no engine modifications required). This process has been tested commercially and is technically successful (see Appendix 1). However the process is not economically competitive with transport fuels from crude oil.

Diesel from natural gas

Diesel can be produced from natural gas following a process similar to that outlined in Figure 8. There are currently five commercial GTL plants in operation worldwide. They vary in size from 14,000 barrels of oil equivalent (boe) per day to 140,000 boe per day (approximately 30 to 300 PJ per annum). As with methanol and DME production, the relative quantities of transport fuels and products made via the GTL process is small (approx. 0.5% of total liquids production). However, the technologies are a commercial reality with long-term contracts for gas in place and with long-term discounts on the gas price. Lifecycle assessments suggest that whole-of-life emissions for diesel produced from natural gas are comparable to those for diesel produced from crude oil.[45] Several factors, such as the geographical location of the resource relative to the processing facilities, the quality of the oil and the technologies used in the processing of the oil and gas can make a small but significant difference to the lifecycle comparison.[46,47,48,49]

Alternative GTL routes to liquid fuels are not practised commercially. However, development work is being undertaken both in Australia and around the world to determine the technical and commercial feasibility of these. See Appendix 1 for more information.

43 China Climate Change Info Net 2006. 'China to build its largest DME project as an alternative to oil which alone will produce 3 Mt per annum.' Available at: http://www.ccchina.gov.cn/en/NewsInfo.asp?NewsId=5739.

44 US Energy Information Administration. Available at: http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&aid=

45 See Kalnes *et al.* 2009 above n 37.

46 Furuholt 1995. 'Life-Cycle Assessment of Gasoline and Diesel.' *Resources Conservation and Recycling* 14(3-4): 251-263.

47 Reinhardt, G.A. and Zemanek, G. 1998. 'LCA of "Rme Versus Diesel Oil" – the present state of discussion', *Landbauforschung Volkenrode* 48(3):, 107-117.

48 Guinee, J.B. and Heiijungs, R. 2007. 'Calculating the Influence of Alternative Allocation Scenarios in Fossil Fuel Chains.' *Intern. J. Life Cycle Assessment* 12(3):, 173-180.

49 See Kalnes *et al.* 2009 above n 37.

We cannot assume that large quantities of natural gas will be available for motor cars or that the price will remain as low as it is today.

3.2.2.4. Peak gas

With peak oil imminent, natural gas is coming under increasing pressure to substitute for the uses of oil in transport and petrochemicals. In addition, as carbon prices become more widespread globally and higher in magnitude, natural gas in combined-cycle power stations will begin to substitute for coal in generating base-load electricity. Additional uses of gas are in the co-generation of electricity and heat and in tri-generation, in which electricity, heating and cooling are provided. Gas is also an excellent back-up fuel for solar hot water, solar thermal electricity and wind power. Therefore, we cannot assume that large quantities of natural gas will be available for motor cars or that the price will remain as low as it is today. Indeed, it is possible that peak oil will be followed within 20 years or so by peak gas.[50,51]

Whilst gas reserves in Australia (and in neighbouring countries) are significant, they are not limitless. Furthermore, contracts are being signed for the export of very large quantities of LNG. There may ultimately be concerns of the advent of 'peak gas', that is, the time when supplies become limited – as they are currently with oil – with consequent impacts on price and availability. So consideration of any transference of gas production to vehicle fuels should reflect on both the finite nature of the reserve, and the value proposition with regard to the use of this resource for other purposes (power generation, export markets).

We make no attempt to do this in this report. However, we have included in the nominal portfolio of actions for motor car fuels developed below, a contribution from gas-to-liquid conversion reducing imported oil dependence by 10% (72 PJ, 2 GL) by 2030. This figure represents the equivalent of an investment in a medium-sized oil refinery, an investment we believe is within the realms of possibility in the next two decades. This notional scenario would reduce greenhouse gas emissions only if the conversion of gases to liquids is without emissions, i.e. with carbon capture and storage. This is supported by the work of Jaramillo et al. (2008).[52] The other factor impacting the availability of natural gas derived fuels for use in vehicles is the availability of facilities to convert the gas to transport fuels as discussed earlier. In all likelihood, gas conversion and GTL processes would not be available to deliver significant quantities of fuel in Australia inside a decade.

3.2.2.5. Coal-to-liquids (CTL) technologies

Coal-to-liquids (CTL) technologies can also be used for the production of transport fuels. Like GTL technologies, CTL technologies produce fuels that can be used without modification to gasoline or diesel engines. Variants on CTL technologies have been used from time-to-time over the last 80 years, particularly in situations where oil-derived transport fuels were not available (South Africa, Germany). The fuels produced by CTL come with a large carbon footprint.[53] Consequently, CTL technology is unlikely to flourish in a carbon-constrained economy without associated carbon storage. It is also unlikely that it can deliver significant quantities of fuel inside 10-15 years. For these reasons, coal-to-liquid conversion is not considered as an option in the notional portfolio of

50 Laherrér 2004. *The Future of Natural Gas Supply.* http://www.peakoil. net/JL/JeanL.html, accessed 2 August 2009.

51 Fleay 2006a. *European Natural Gas: The global context.* Australian Association for the Study of peak oil and gas, http://www.aspo-australia.org.au/References Fleay/EuropeUK%20 Gas4-06.pdf, accessed 2 August 2009.

52 See Jaramillo *et al.* above n 40.

53 Ibid.

actions considered below. As for GTL technologies, this does not mean that ongoing research and development should be discontinued. On the contrary, investment in such options is one way of maintaining a more diverse set of possibilities, despite current uncertainties.

3.2.3. Transport fuels from biofuels

Biofuels are fuels derived from carbon and hydrogen containing compounds formed annually in the photosynthetic and metabolic processes of plant and animal species, converting the energy of the sun into chemically stored energy.

First-generation biofuels are based on starchy seeds, such as corn or wheat, or sugar, that when fermented produce bioethanol. Or they can be based on oil seeds, such as sunflower that when pressed yield oil to be used as biodiesel. Some fuels can be made from animal products such as tallow that similarly yield oil-based fuels for use as biodiesel. Solid biomass, such as wood, grass and agricultural waste can be dried and pelletised to form a solid fuel (but this is of little relevance to motor vehicle fuels), or gasified in a process similar to coal gasification to potentially provide transport fuel (see Figure 8).

Biofuels thus include vegetable oil, biodiesel, bioalcohols, bioethers, biogas, and syngas produced from biomass and solid biomass. First-generation biofuels have come under significant criticism because their low efficiency of production (litres per hectare) places them into direct competition for agricultural production otherwise used for food and fibre.

A common pathway to liquid or gaseous biofuel production is to grow crops high in sugar (e.g. sugar cane, sugar beet) or starch (corn, wheat) from which ethanol or other alcohols such as butanol are produced using fermentation. Alternatively crops can be grown that produce large amounts of vegetable oil (e.g. soybean, oil palm, jatropha, algae) that is extracted under pressure. This oil can be burned directly or processed to produce biodiesel. In each case, this involves the conversion of existing food-producing land to fuel production, or demands the expansion of crops into new areas. A significant factor in these processes is that they lend themselves to relatively small-scale and decentralised processing facilities.

Second-generation biofuels are defined as those that are based on non-food crops/products such a cellulose materials and thus do not necessarily impinge on food production, although they may depend on the waste biomass from the food production systems, potentially enhancing the overall value of these systems. Second-generation biofuels depend more specifically on the use of wood products or non-edible, often waste, products from existing agricultural or forestry activities using cellulose fermentation to produce ethanol or gasifying the biomass to produce syngas from which liquid fuels can be produced.

Methanol can be produced by gasifying woody vegetation to produce a synthesis gas composed of carbon monoxide and hydrogen. By means of a second process, this is then converted into methanol. Incidentally, a by-product – biochar – is a soil improver that can improve plant growth and carbon sequestration properties of soil. The process of producing bio-methanol is well developed and essentially the same as converting natural

Biofuels should be a component of the fuel mix and this component could probably grow to around 10% of motor car energy demand by 2030.

gas to methanol. A recent study by Foran[54] uses a biophysical-economics model to present the case that Australian farmed landscapes be 're-clothed' with trees to combat dryland salinity, and provide a new enterprise for farm businesses through transport biofuel production. Foran concludes that bio-methanol production is preferable to second-generation bi-ethanol on several grounds:

- The production technology for methanol is more advanced;
- Methanol, a petrol substitute, can also be converted readily to DME, a diesel substitute;
- Methanol is also a valuable industrial feedstock and could be used as a hydrogen carrier in a future hydrogen economy.

The deliberate cultivation of algae for biofuels is a special case. These crops have the capacity for higher rates of solar energy conversion (perhaps ~10%) than many agricultural crops (<1%) and do not necessarily compete with food cropping. This higher than usual efficiency of conversion of solar energy means that in principle smaller areas dedicated to algal production might deliver significant liquid fuel production. Current production of fuel in this manner is insignificant and in the exploratory stage. The capacity to deliver future liquid fuel in this way is not only a matter of the area available, but also the capacity to maintain highly efficient production systems (ongoing water and nutrients; in particular, nitrogen) without undesirable impacts from diseases or without unwanted cycling of nitrogen back into the atmosphere as the greenhouse gas nitrous oxide. National and international research and development should continue so that the viability of such intense systems can be ascertained and so too can the economic cost of fuel production in this way. In the meanwhile, for the development of the notional portfolio of actions below, algal production of fuels is considered to be of insufficient potential to be included.

The role of biofuels in future energy markets has been an issue of contention and wide discussion in the literature over recent years. Within the Jamison Group we share a common view that biofuels should be a component of the fuel mix and that this component could probably grow to around 10% of motorcar energy demand by 2030. However, we have varying views concerning how such an industry might be constructed. Our differences reflect perhaps those in the wider research community and arise from uncertainties that exist for any one or more of the following reasons:

- **Agricultural capacity:** The capacity to deliver fuel demand and emissions reduction through biofuels is limited by the low efficiency of conversion of solar energy, land available for appropriate agriculture, climatic conditions and how they may change with global warming, soil types, distance to market, human resources, and the competing demands for land use and its economic value. To provide a perspective on the magnitude of agricultural production that would be needed to contribute to national motor car fuel demand, one can consider current national production of wheat, sugar and forest and wood products. If transferred to fuel production, these would contribute to a reduction of no more than 20%, 8% or 0.2% respectively of the current national motor vehicle fuel usage, emphasising the magnitude of the agricultural conversion required to have a major impact on meeting the demand for motorcar fuel.

54 Foran 2009. *Powerful Choices: Transition to a biofuel economy in Australia.* Land and Water Australia, Canberra. http://lwa.gov.au/files/products/innovation/pn30178/pn30178.pdf.

- **Net energy contribution:** The net energy available at the farm gate can be as little as 50-70% of the energy within the crop product because of on-farm energy consumption. This excludes energy required for the production of fertilisers, transformation of product to fuels and off-farm transportation.
- **Climate change:** Examination of the most probable outcomes of climate change in Australia[55] suggests that for most of the continent, rainfall is likely to decrease by 5-10% through this century with concomitant increases in evaporation, impacting on water availability. Thus, there is uncertainty about the viability of productive systems in Australia, their location, potential for adaptation to change, and co-availability of suitable soil types.
- **Competition for land:** The net value to farmers of food and fibre products currently exceeds the likely value of fuel products (subject to subsidy), but this will change in time as fuel prices change. Suitable land for agricultural production will rarely be co-located with facilities for conversion to biofuels, or where the biofuels will be used. These are factors that impact on estimates of the economic costs, beyond those of agricultural production, in ultimately delivering biofuels to market. On the other hand, growing feedstocks in rural areas for local processing into biodiesel for local consumption in farm or mining operations may be attractive. Existing land-use practices and agricultural systems are adjusted to current demand for products for local and international usage. The conversion of these lands to potentially different purposes, together with the infrastructure required to handle these products and convert them to fuels, may impact on such trade and, in any case, could not happen instantaneously.
- **Greenhouse gas emissions:** Agricultural systems do not act as 100% recyclers of carbon. Carbon dioxide emissions occur at initial land clearing (can leave a net legacy of emissions for decades to centuries), during the production of fertilisers, though the depletion of soil organic matter, through on-farm energy use and off farm transportation, processing to fuels and the decay or combustion of crop product. Potentially as important is the full life cycle of nitrogen. Atmosphere molecular nitrogen is captured in the formation of fertiliser. Through direct leakage of applied nitrogen or ultimate processing or combustion of the fuel it can be released as nitrous oxide into the atmosphere, a gas which is 300 times more potent as a greenhouse gas than carbon dioxide. In a world where emissions may become accounted for in an emissions-trading scheme this is important as it may exacerbate the national emissions inventory or incur costs for the right to emit and thus impact on the real costs of such fuels.
- **Projected costs of production:** The annual commercial value of wheat, sugar, wood and forest products to the Australian economy is $1,900, $177 and $120 per tonne of product respectively (2007-08).[56,57] This is equivalent to approximately $180, $7 and $50 per kilojoules of energy for these crops respectively and their market value in current usage. This compares with the current Australian retail price of electricity of approximately $0.04/MJ (14.4 c/kWh) and the retail price of petrol of $0.03/MJ ($1.04/litre). An examination of the promotion of alternative transport fuels made from agricultural commodities[58] concluded that the level of subsidies in the US, Canada and the EU in 2006 was about US$11 billion, a figure estimated to grow to $25 billion by 2015. The report identified a range of different forms of support to the biofuels industries in these countries including budgetary support (such as tax concessions), blending or use of mandates requiring biofuels to represent a minimum share or quantity in the transport fuel market and trade restrictions (mainly in the form of import tariffs, protecting the less cost-efficient domestic biofuel industry from competition from lower-cost foreign imports). The study concluded that there are alternatives to current support policies for biofuels that would more effectively allow governments to achieve their objectives.

Rarely do studies venture to address all of these issues concurrently and we do not attempt to do so here. We therefore strongly support the idea of a much more comprehensive holistic study of the biofuels issue as part of the on-going strategy. We make some cautiously positive proposals in Section 4.4 below.

55 CSIRO/Bureau of Meteorology 2007. *Climate Change in Australia*. CSIRO and Australian Bureau of Meteorology. Technical Report, ISBN 97819211232930. Available at: www.climatechangeinaustralia.gov.au.

56 ABARE 2007. *Australian Forest and Wood Products Statistics*. September and December quarters, 2007. www.abare.gov.au/interactive/08afwps_may/index.html.

57 See ABARE 2009b above n 17.

58 Organisation of Economic Cooperation (OECD) 2009. *Biofuel Support Policies: An Economic Assessment*, Report of the Organisation of Economic Cooperation and Development and the International Energy Agency.

4. Potential fuel options/scenarios

The need to guarantee ongoing supply of fuels for motor vehicle transport, while reducing greenhouse gas emissions, demands a comprehensive portfolio of actions. The notional portfolio suggested here is not without uncertainties, particularly in relation to the magnitude of change that can be delivered and the timeframe in which that delivery can take place. Nevertheless, each component of the portfolio identifies significant opportunities and offers grounds for developing these opportunities.

An important first step is to reduce demand for car transport and conventional transport fuels.

Building security of supply and simultaneously delivering emissions reductions from the transport sector requires a complex interaction of a range of options. Due to the complexity of factors involved, the rate of uptake and cost of each option can only be assessed with significant uncertainties. Indeed, it is this uncertainty that cries out for a comprehensive approach, commonly called a portfolio. Such an approach maximises the chance of delivering outcomes and protecting against unforeseen problems; that is, it manages this risk.

In this section we describe a portfolio of actions of which all components need to be considered as a part of a national strategy specifically addressing motor cars. **This notional portfolio or scenario is not intended as a prediction**; this would require a much more substantive and cross cutting study. We hope that it will illustrate the nature of such a portfolio and identify many of the issues that need consideration in the formulation of a portfolio as the basis for policy development. The components of this portfolio follow in Section 4.1 to 4.5.

4.1. Demand reduction

An important first step to the overall management of fuel security and emissions reductions is to seek every opportunity to reduce demand for car transport and conventional transport fuels. Demand relates closely to our way of life, our aspirations and the nature of the community in which we live. These are boundary conditions that are difficult to change, but recent experience such as the response of the community at large to water shortages shows that some contributions through demand reduction can be made in relatively short periods of time. The following are opportunities for bringing about demand reduction:

Public awareness related to:

- Responsible choice in terms of limiting unnecessary trips through planning, use of walking, bicycling and car pooling;
- Improved planning for, or reduced use of, vehicles for multiple short trips such as the delivery and pickup of children from schools and unnecessary multiple trips to shopping locations; and
- Improved driving skills that limit unnecessary fuel demand and add to vehicle fuel performance.

First there is a need to begin a process of public education and information exchange to strengthen both the rationale for behavioural change and to provide clear indications of personal options for citizens. This starts with the development of the concept of responsible motoring. This involves an understanding that the use of a motor vehicle contributes to the national issues of security of supply and greenhouse gas emissions and that personal actions with regard to vehicle use can contribute to the national interest. These personal actions include more careful planning of vehicle use such as the avoidance of multiple trips when planned single trips can perform more tasks; the sharing of trips with others; limitation of long-distance motoring; and driving behaviour that maximises fuel efficiency.

Action by the Australian Government in terms of legislation of more efficient vehicles (discussed in the next section) does not preclude the desirability of unilateral actions by state and local governments in the setting of self-imposed targets for motor vehicle use. In many cases these provide for the rationalisation of transportation costs within the jurisdiction, as well as setting examples to the respective communities in terms of how to reduce transport demands.

A reduction of motoring demands can be made by individuals personally seeking alternative transport options. Such options include greater use of walking and bicycling for visiting retail outlets and for recreation where walking would be a clear option with other potential benefits (peer socialising, exercise, road congestion reduction, household need for two or more vehicles, etc.).

This option will require public education through governmental and interested groups (such as motor car associations) and promotional programs to shift from current behavioural paradigms. It will also be supported by the provision of conditions conducive to alternative transport options.

Increased use of public transport:

- Significant increased use of public transport as an option for commuting and recreational activities; and
- Town and road planning.

This option may occur as a result of economic changes related to increased pricing of fuels and parking or other measures such as congestion charges, but will also require encouragement for a paradigm shift in broadly held attitudes to public transport. Its capacity to deliver will also depend on government programs related to town planning, particularly around the densification of built-up areas, the reduction of city fringe development and the investment in rail links and more frequent services. It is also important to note that movement towards public rail travel can be very important in terms of liquid-fuel demand. The impact of rail on emissions depends on the choice of fuel, be it diesel or electricity and whether the electricity is generated from wind, hydro, solar, black coal or brown coal (see later discussion on electric cars). It also depends on the effective loading of the transport system to near capacity as frequently as possible and the level of back loading to avoid trips where vehicles are empty or poorly loaded. This requires more intelligent planning of the use of trains, truck, taxies, etc. on their return from delivery trips.

Transport demand depends very significantly on the structure of the urban environment: the disposition of home, work and recreation; traffic management and flow. At any point in time this reflects the accumulated outcomes of previous policy decisions and town planning. Intervention into these processes can assist strategically in bringing about future conditions that diminish the demand for motor vehicle transport and therefore lessen the risks associated with it.

The case is strong for the wider use of public transport; in particular, rail travel that can avoid the use of liquid fuels entirely. Whilst the advantage of public rail travel with regard to greenhouse gas emissions avoidance is less clear, dependent on the source of electrical energy and passenger loading, there are a number of potential co-benefits associated with public transport including improved city air quality and public health, reduced number of road deaths, and lower road congestion. Such co-benefits are rarely rigorously considered in analyses of transportation options, partly because they render themselves less easily assessed in terms of economic parameters.

Motor vehicle choice:

The most significant impact an individual can have on their own fuel demand and greenhouse gas emissions is in their choice of motor vehicle. Such choices are made in the context of a complex of socio-economic and behavioural preconditions. Until recently fuel consumption has rarely been a major pre-determinate of motor vehicle choice. However, recent experience of periods of higher fuel prices has demonstrated, on the one hand, little propensity to reduce driving distances, but on the other, a substantial shift in purchasing preference towards smaller, hybrid and diesel vehicles. This component of the portfolio will be discussed further under technology options below.

The lack of information concerning embedded energy in the production and disposal of motor vehicles complicates

The most significant impact an individual can have on their own fuel demand and greenhouse gas emissions is in their choice of motor vehicle.

any decision by a concerned purchaser concerning the relative energy efficiency of one vehicle compared with another over its full life, manufacture to disposal. A vehicle that consumes relatively little energy in its operations might not necessarily be the best choice in terms of minimising total energy use and emissions over its life, if its manufacture and/or disposal involves large amounts of energy.

The total energy required through the lifetime of the vehicle is the sum of the energy used (embedded) in its manufacture (and recycling) and its subsequent fuel consumption. The former may be relatively small compared with the latter but it remains an issue (if not a distraction) in terms of informed consumer choice at the time of vehicle purchase. This distraction is partly due to the widely divergent estimates of energy used in the manufacture of vehicles that reflect the different assumptions used to make the calculations.

In a comprehensive assessment of the energy used in the full life-cycle of an internal combustion engine motor car, Burnham *et al.*[59] show that energy embedded in its manufacture to be approximately 30×10^{10} J or 83 MWh (1800 BTU/mile for a life of 160,000 miles). If the average life of a car is assumed to be 10 years, this is equivalent to continuous energy consumption of 1.0 kW (24 kWh per day). Burnham also estimated the energy content of the fuel consumed in the full life of the vehicle to be 39 kWh (4500 BTU/mile; 1.6 kW continuously).

These figures are relevant for several reasons. First, despite the assumptions made in the Burnham *et al.* analysis, their estimated daily energy use in the fuelling of a motor car compares well with an estimate based on vehicle use of 15,000 km per year (at a current average consumption rate of about 10 L/100 km and an energy content of petroleum of 0.34×10^8 J/L) giving a rate of energy use of about 1.7 kW or 41 kWh per day.

Second, the energy content in the manufacture of the vehicle is equivalent to that used in driving the vehicle for about 6 years ($30 \times 10^{10}/5.4 \times 10^{10}$). From an energy or emissions perspective an advantage in the more frequent recycling of vehicles will only occur when the net difference between the operational energy (or emissions) of a replaced and a new vehicle exceeds the energy content of the manufacture of the new vehicle. Thus when replacing a vehicle with one that is 50% more energy (emissions) efficient, it will take about 10 years before the use of that car will compensate for the energy required to build it. Or, if the new car is only 25% more efficient, it will take close to 20 years. For this reason, the forced retirement of less efficient vehicles which may be a desired policy position for other reasons, is not a particularly effective way of improving the net impact of vehicles on total energy use (or emissions) over time.

Third, and interestingly, it shows that the energy used in the operation of a motor car compares with the embodied energy consumption in the shell[60] of an average (UK) three-bedroom house – estimated at around 46 MWh or 2.3 kWh per day[61] with that of the average household. The energy consumed in the manufacture of the vehicle, given the assumptions contained herein, is similar to that of an average Australian household (estimated at around 1 kW). These comparisons are summarised in Table 4.

Table 4: Comparison of energy quantities incorporated in motor vehicle manufacture and operation.

Item	Energy quantity	Equivalent continuous rate of energy flow (kW)	Source
Solar energy incident on Australia	22×10^6 J/ m^2 /day	0.25 per m^2	Appendix 4
Operation of a car (360×10^4 J/km; 15,000 km/year)	5.4×10^{10} J/yr	1.6	Appendix 4
Operation of a car (160,000 miles; 10 years)	7.6×10^{10} J/yr	2.4	Burnham *et al.*[62]
Embedded energy	3×10^{10} J/yr	1.0	Burnham *et al.*
Embodied in three-bed home	1.7×10^{10} J/yr	0.5	Mackay
Approximate Australian home	3.1×10^{10} J	~ 1.0	

59 Burnham, A., Wang, M. and Wu, Y. 2007. *Development and Application of GREET 2.7. The Transport Vehicle-Cycle Model.* Argonne National Laboratory Report. ANL/ESD /06-5, Argonne. p. 24. Available at: http://www.transportation.anl.gov/pdfs/TA/378.pdf.

60 The shell of a building is its roof, walls and floor.

61 MacKay 2009. *Sustainable Energy – without the hot air.* UIT, Cambridge UK, p. 324.

62 See Burnham *et al*, 2007. above n 59.

In order to satisfy greater levels of energy demand and greenhouse gas emissions reduction, there needs to be additional government intervention at all levels.

Whilst the potential contribution demand reduction can make is believed to be very significant in principle, in practice, because of the inertia of behavioural and infrastructure change, the contribution to the reduction of energy use and emissions over the next two decades is important but limited. Thus for the purpose of our notional scenario, we have modelled demand reduction as contributing to a lowering of motor car use below the BITRE[63] projections over the next 10 years by 10% and in the next 20 years by 20%.

4.2. Intervention via new vehicle fuel consumption targets

Demand reduction requires government intervention to provide improved infrastructure for public/rail transport, cycling and walking and to give motorists incentives to reduce their demand. In order to satisfy greater levels of energy demand and greenhouse gas emissions reduction than achievable by the demand reduction outlined above, there needs to be additional government intervention at all levels. There is a need for national and regional setting of targets for the reduction of motor vehicle use and the increased use of public transport. As part of the Australian Government's commitment to international actions on climate change, national motor vehicle fuel consumption and greenhouse gas emissions targets should be established at the same time as the Carbon Pollution Reduction Scheme targets. These should aim to bring Australia's motor fuel consumption standards in line with the established standards in the European Community[64] within five years (see Appendix 3).

We see intervention in particular as a necessary condition for the achievement of all components of the portfolio for the reduction of liquid-fuel usage, and consider intervention as likely to produce the most important results. We recognise that such intervention will impose requirements on the manufacturing industry which may or may not be readily accepted. But these imposts need to be assessed not only in terms of that industry, but also in terms of the multiple goals of decreased dependence on imported fuels, reduced greenhouse gas emissions, improved public health and decreased vulnerability to disruption of supply; that is, a number of public-good and economically valuable outcomes. At the same time, we see this intervention as part of the re-positioning of the Australian automotive manufacturing sector to produce cars that are likely to be in demand into the future for both national and international consumption.

For the purpose of establishing our notional scenario, we have proposed that the latest EU consumption standards be adopted in Australia, albeit with a slightly delayed introduction, reflecting the current relatively high energy use and emissions levels of cars manufactured and sold in Australia and reaching parity with the EU by 2015. Table 5 shows the notional introduction of standards for all manufacturers selling cars into the Australian market, cognisant of the need for rapid change, the inertia of the characteristics of the existing fleet, consumer preference and the impost on manufacturers to undergo such changes.

63 BTRE 2005b. *Greenhouse Gas Emissions from Australian Transport. Base Case Projections to 2020*, Report for the Australian Greenhouse Office, Department of the Environment and Heritage. Available at: http://www.bitre.gov.au/.

64 EU Commission Regulation (EC) No 443/2009 of April 23 2009 of the European Parliament and of the Council. *Setting emissions performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light duty vehicles.* Official Journal of the European Union, L 140: 1-15. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0001:0015:EN:PDF.7.

Whilst the main component of government intervention would be the introduction of emissions and fuel consumption targets for manufacturers (which should be linked with current government economic support for the industry due to global financial crisis), there are other areas of intervention that would also assist in this overall process. These relate to promoting conditions that make the transition to vehicles meeting these standards and include the removal of taxation relief for businesses that promote both the purchase of larger vehicles and their greater use (kilometres driven), including the diesel excise rebate. The changing federal transport funding mix for road:rail from about 9:1 to 1:1 would also be of assistance.

Appendix 4 shows how the impact of these first two components of the portfolio of actions (demand reduction/management and the setting of fuel consumption targets) was calculated. The impact of these components on projected energy and fuel volume demand as well as CO_2 emissions is discussed in Section 4.5 below.

4.3. Technology changes

Achieving significant reductions in liquid-fuel usage over the next 10 to 20 years through the setting of emissions and fuel consumption targets will involve a range of technological changes in the motor vehicles themselves. Some of these changes have already commenced over the past decade or so but need to be encouraged, promoted and supported through intervention of the kind mentioned above. Such changes need to be considered in the context of the existing motor vehicle fleet and its current rate of turnover (average vehicle lifetime of approximately 11 years) when estimating the potential to contribute to lowering fuel usage. We anticipate that technological changes will include vehicle size, hybrid drive, electric drive, dedicated gas vehicles, and gas retrofit.

Table 5: Summary of the European Union motor car emissions standards (See Appendix 2) and notional standards for Australia as used in this scenario development process.

		2012	2013	2014	2015	2016	2017	2018	2019	2020
European Union	g CO_2/km	130	130	130	130	95	95	95	95	95
	% of manufacturer's fleet sales	65	75	80	100	T/A	T/A	T/A	T/A	100
Australia	g CO_2/km	N/A	N/A	130	130	130	130	95	95	95
	% of manufacturer's fleet sales	N/A	N/A	65	100	100	100	75	80	100

Vehicle size: A highly effective way of reducing fuel demand is to reduce vehicle mass. Australian vehicles on average are significantly larger than their European counterparts and this in part contributes to our disproportionate fuel demands. There has been a strong swing towards the purchase of smaller vehicles in Australia for the last several years and this trend should be encouraged. For example state governments could lower registration fees for smaller cars and fund that by increasing registration fees on large cars, although there are equity issues that are important to consider here. Government car fleets could have a greater proportion of small cars.

Hybrid drive: The combination of smaller internal combustion engines with electric drive systems offers a number of advantages that have the potential to lower fuel usage, especially for urban driving. These include more optimal operation of the internal combustion engine with lower fuel consumption and air quality advantages; the retrieval of kinetic energy during braking; and improved torque at low speeds.

The success and future of hybrid-drive and electric vehicles depends significantly on battery technology.[65] This has improved greatly since the EV1 model mass-produced by General Motors Corporation in 1995, which relied on lead-acid battery technology. Hybrid-electric cars such as the Toyota Prius

65 See Jamison 2010. Above n 26.

Hybrid-drive vehicles are likely to be a significant part of the strategy to achieve consumption reductions over the next decade or so.

have employed nickel-metal-hydride (NiMH) technology for electrical energy storage, and more than one million Prius models have been sold. As the most recent entrant to car making, Chinese battery company Build Your Dreams (BYD) is reported to be producing 13,000 cars per month using lithium-iron-phosphate battery technology. The BYD electric car is earmarked for release in the US for the end of 2010. Lithium-iron-phosphate is the technology most favoured by prospective electric vehicle designers because of its high energy density, reliability and recyclability and lower risk of thermal runaway.

Electric drive: The roadmap suggested in Jamison (2008) indicated our expectations that over time, motor vehicle transportation will be based on electric drive. There are several limitations to the practicalities and rate at which this technology can be taken up and these are discussed in Jamison *The Electric Vehicles Revolution* 2010. They include the current limitations of battery technology which influences the range and frequency of recharging, the absence of a network of battery recharging or exchange points, the rate of recharging, and the lifetime and cost of the batteries themselves. Whilst the move towards electric drive motor vehicle technology would seriously lessen the demand for fossil fuels, the impact on greenhouse gas emissions depends significantly on the sourcing of the electricity (see Figure 14 below). These and other issues are developed in Jamison *The Electric Vehicles Revolution* 2010. Our conclusion, however, is that through the period of the next 20 years the contribution from electric-drive vehicles will grow strongly, albeit to a maximum contribution to the reduction of fuel usage of less than 20%. By that time, for the purpose of the notional portfolio, we suggest that electric-drive vehicles may constitute 33% of the fleet and make up 64% of all new car sales. Hybrid-drive vehicles are likely to be a significant part of the strategy to achieve consumption reductions over the next decade or so. However, we are of the view that this will be a transitional period that will be overtaken by the uptake of fully electric drive vehicles.

Dedicated LPG vehicles: Dedicated LPG vehicles have proven to be unpopular with the consumer and despite being made available by one manufacturer, the uptake of such vehicles has been slow. This could be changed through intervention such as the implementation of emission and/or consumption targets for the car manufacturing industry in Australia and through the application of improved energy technologies to further increase the efficiency advantages delivered by LPG combustion. Our portfolio includes slow growth in dedicated LPG vehicles, associated with government policies on emission standards, the implementation of new LPG combustion technologies into Australian manufacturing, and changed community perceptions about the desirability of such vehicles. We see such vehicles having a steadily growing impact on the demand for oil but with their greatest impact beyond 10 years from now given the lifetime of the average car in the fleet.

Efficient LPG retrofit: Current Government policy in promoting the retrofitting of motor vehicles to use LPG[66] has led to an increase of such vehicles by 1.4% of the total fleet. This has had the effect of reducing the use of petrol by 0.6% for the vehicles converted since the advent of the LPG conversion subsidy in 2006. In other words, the substitution of petrol for LPG since the government policy promoting LPG retrofits means these cars that would otherwise be consuming petrol are now consuming LPG instead. (This figure is based on the average petrol or diesel

66 LPG Autogas 2006. Consumer Demand drives autogas expansion. 30 November 2006. Available at: http://www.lpgautogas.com.au/index.cfm?action=News&unq=102&Type=R.

This could be a boon for Queensland rural industries, for rural incomes, and for Australia's energy independence, supplying 10% of our liquid fuel needs.

vehicle being driven 15,000 km per annum with a fuel consumption of 10 L/100 km.) The advantage of LPG retrofit is that the technology is currently available, Australia is relatively well resourced in LPG, the effect on greenhouse gas emissions can be substantial if CO_2 emissions associated with the extraction of LPG can be sequestered, and significant inroads on oil use can be made in a relatively short time. We suggest that a portfolio should include a target for the conversion of 10% of the current fleet to LPG in the next five years. Thereafter the impact of dedicated LPG vehicles will become more important.

It is worth mentioning here that LPG is not taxed by the Federal Government and will not be until 2011, when an excise of 2.5 c/L of fuel sold will be charged. This excise will step up to 12.5 c/L by 2014. This could have an impact on the uptake of LPG vehicles.

We are of the view that the use of LPG (and LNG) for motor vehicle transport is necessary in the short term as a way of delivering fuel security and, potentially, emissions reductions. In the longer-term (beyond 20 years), however, we do not see the use of LPG or natural gas as major options for transportation. This is in part because gas will come under increasing competition for alternative uses and because ultimately there is a limit to the level of reduction of greenhouse gas emissions that can be made using such technologies. These factors should not deter current investment in LPG and gas options because the longer-term is well beyond the lifetime of the average motor vehicle although it may influence the level of investment that will be made in these technologies by manufacturers.

We are confident that a combination of these technology options will provide manufacturers with the opportunities to meet the targets of reduced fuel consumption and emissions as described above.

4.4. Fuel change

Apart from the use of LPG and natural gas as alternatives to petrol and diesel in the Australian motor vehicle fleet, other options that need to be incorporated in our portfolio are as follows:

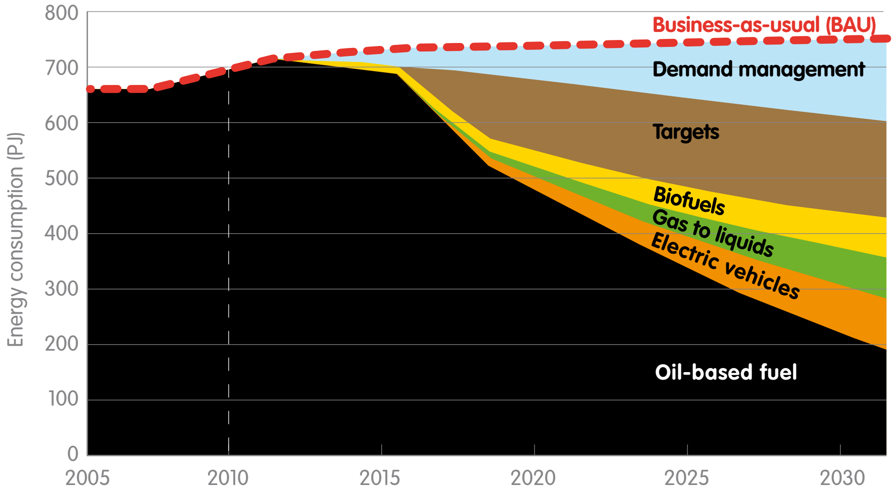
Gas to liquid: Australia's significant endowment of natural gas resources means that opportunities exist with regard to the direct use of gas as a transport fuel, as described above, or potentially for the conversion of gas to liquid fuel. The potential of this to contribute to our energy mix is seen to be small during the next 10 years given the current technology shortcomings and costs, but will contribute approximately 3% to demand reduction by 2020 and 10% by 2030.

Diesel: Modern technology has substantially improved the environmental performance of diesel motor vehicles, particularly with respect to their emission of particulate matter. These cars achieve significant reductions in fuel consumption and CO_2 emissions compared to their petrol-driven counterparts. The uptake in diesel motor vehicles in Australia has increased markedly, albeit from a small base, in recent years. The fact that diesel engines are generally around 20% to 25% more fuel-efficient than petrol engines means that greenhouse gas emissions are lowered to a similar extent. However, as a proportion of overall greenhouse gas emissions from transport, the reduction is less than 1%. Nonetheless, it must be acknowledged that the increased take-up of diesel-fuelled cars makes a contribution to lowering Australia's energy imports. The capacity for diesel technology to continue these improvements is ultimately limited, however, due to the security-of-supply issue, the availability and price of diesel, and the limits on how much greenhouse gas emissions can be reduced with this technology. We see the continuation of the trend in the use of diesel motor vehicles in Australia over the next five years as contributing in a small way to the reduction of overall oil demand.

Biofuels: In this document we have considered at some length the potential for biofuels to contribute to Australian fuel demands and greenhouse gas reduction targets over the next 10 to 20 years. We have identified several factors that present significant impediments to the widespread uptake of biofuels as a major option. On the other hand we propose in our 'notional scenario' that domestically produced biofuels might be able to meet 1 GL of Australian fuel demands by 2020 (5%) and 2 GL or 10% by 2030.

In Jamison (2008) we specified that biofuels should not come from wheat but from sugar cane (because its productivity in terms of land required is twice as high). In this way 1 GL of ethanol could be obtained from biorefineries in Queensland producing 200 ML per annum each and each drawing on an area under sugar cane of 50,000 ha. Five biorefineries would be needed to produce 1 GL of ethanol and would draw on sugar cane grown on 250,000 ha. Current Australian sugar cane is grown on 400,000 ha so an initial 1 GL of ethanol could be produced from existing sugar cane crops without the need for extra land. One idea is for farmer cooperatives to build the ethanol biorefineries. This could meet our 2020 target. To reach the 2030 target of 2 GL, we envisage as one possibility a doubling of the present sugar cane industry in Queensland to reach 800,000 ha under tropical cultivation without any clearing of virgin bushland, of which 300,000 ha could be kept for sugar and 500,000 ha for ethanol, eventually allowing Queensland farmers to produce a substantial quantity of Australian grown and produced ethanol by 2030. We made the point in Jamison (2008) that this could be a boon for Queensland rural industries, for rural incomes, and for Australia's energy independence, supplying 10% of our liquid fuel needs.

Figure 10: Energy consumption from liquid fuels to meet anticipated increased demand of car transport over time (next two decades). Top curve is the Business-as-usual future and successive curves show contributions to consumption reduction due to components of the notional futures scenario.



We continue to see this as potentially a viable way forward for biofuel production in Australia, subject to the caveats that the program should be: adequately audited to ensure that any lands converted to sugar production are already cleared to ensure that no bushland or forest is cleared for cane production, thereby releasing its stored carbon; a detailed economic analysis is undertaken to ensure that this pathway for sugar production leads to viable economic outcomes in terms of the final cost of the fuel and the value to the farmers; and, this approach stands up in competition for alternative approaches such as those suggested by Foran (2009).[67] It also bears underlining that we do not think any cleared lands should be converted to sugar cane growing in Queensland without a full public inquiry beforehand into the full ramifications of the shift, taking into account the proposed growing methods, soil state and reclamation, potential climatic changes and other matters pertaining to sustainability.

67 See Foran 2009. Above n 54.

4.5. Possible future

We have constructed a notional scenario for the future provision of motor vehicle fuel as an illustration of how a range of complementary options can be considered holistically. What we have been unable to do, and what remains to be done, is to rigorously evaluate the uncertainties surrounding each option (the economics over time, technical feasibility, rate of implementation, social and environmental dimensions). Such an analysis is essential, because it would:

- Underpin policy development which builds on current knowledge and recognises these inherent uncertainities;
- Build a portfolio of actions that provides flexibility and thus resilience through time as we respond to the unfolding future; and
- Provide options that are more likely to simultaneously deliver co-benefits and multiple outcomes.

We believe, however, that the current analysis provides guidance as to how this might be done and indicates the potential for such a portfolio to deliver solutions to the multiple challenges associated with Australia's motor vehicle fuel requirements.

Details of how each component of the notional scenario was developed are provided in Appendix 4 and we will now discuss some of the implications of these calculations.

Future energy demand: Figure 10 shows the evolution of energy demand for motor car transport in Australia through to 2030. Business-as-usual shows slow incremental growth in demand as defined by BTRE,[68] mainly determined by anticipated population growth, from current levels of about 700 PJ to about 750 PJ per annum in 2030. It is beyond the scope of this report to comment on the assumptions

68 See BTRE 2005b. Above n 63.

The fact that diesel engines are generally around 20% to 25% more fuel efficient than petrol engines means that greenhouse gas emissions are lowered to a similar extent.

built into the BTRE projections but it is important to note that these projections are based on population growth rates of less than 2% per annum. Should growth be closer to that experienced over the past years (~2.3%), then by 2030, the BTRE projections would underestimate demand by more than 10%. This emphasises that any policy decisions related to population growth will have significant consequences for future energy demand and thus the range of issues, balance of trade, security of supply, greenhouse gas emissions, among other points, examined in this report.

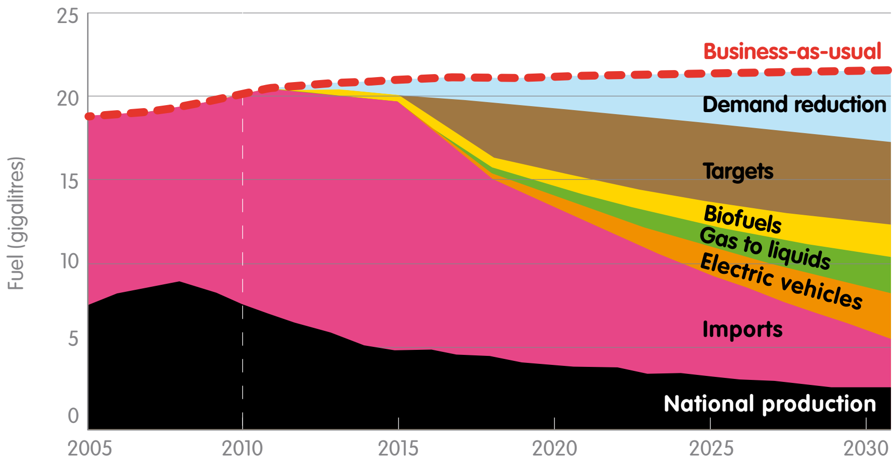
Demand reduction through the many avenues discussed above reduces the energy requirement to about 600 PJ per annum by 2030. Demand reduction is modelled in this notional portfolio as having the potential to bring about early, albeit modest, energy reductions.

With the implementation of new and improved technologies (aside from electric vehicles) to meet fuel consumption targets (as defined for Australia in Table 5), energy demand is reduced by a further 140 and 170 PJ per annum by 2020 and 2030 respectively. The development of a biofuels industry is also seen as having an early role to play in energy-demand reduction, leading to an overall reduction of about 35 and 70 PJ per annum by 2020 and 2030 respectively. The infiltration of the market with electric vehicles as a specific form of technology change is modelled to contribute to a demand reduction of 30 and 90 PJ per annum by 2020 and 2030 respectively.

The options in this portfolio of actions combine to project an overall demand reduction from BAU oil by 2030 of about 560 PJ per annum (-75%) to 190 PJ per annum.

Future liquid fuel volume demand: Concomitant with the energy demand reductions shown above is reduced demand for liquid fuels, one of the key objectives of this strategy. Figure 11 shows the volume

Figure 11: Volume of liquid fuels required over time to meet anticipated increased demand for car transport. Top curve is the Business-as-usual future and successive curves show the contributions to volume and the reduction of volume demand due to components of the notional futures scenario. Also indicated is the contribution to fuel demand from imports and national production.



of fuel required to meet business-as-usual demand grows from about 20 to 21.5 GL per annum by 2030 and, as with Figure 10, shows the relative contribution to this reduction of each component action of this notional portfolio. Combining these options with the maintenance of a national production capacity, albeit diminishing in line with reduced national production capacity[69] the demand for imported oil could be reduced to about 3 GL per annum over the next two decades.

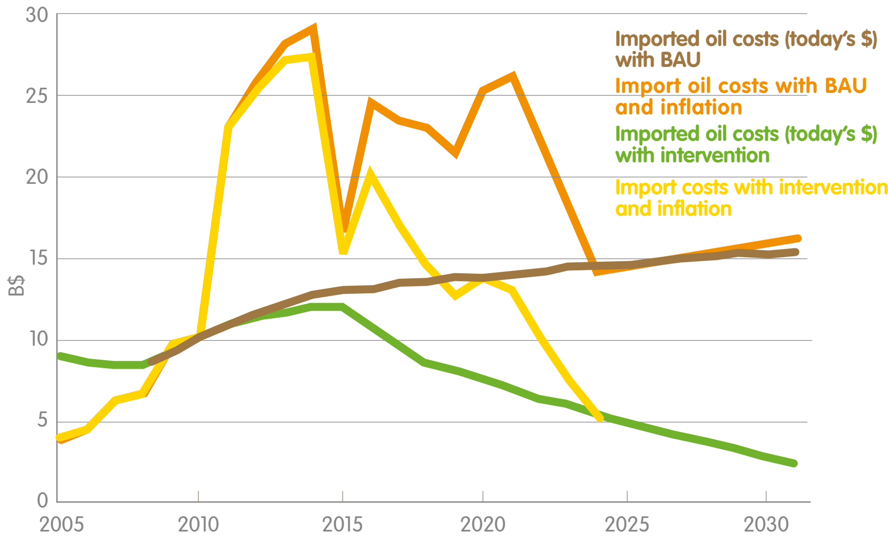
The present net value of imported oil for all transport types is about $10 billion per annum (see Table 1). We assume for this analysis that a similar set of actions in the commercial and industrial transport sector (trucks and light delivery vehicles) could reduce imported requirements and greenhouse gas emissions by similar amounts as for motor cars, but recognise that these are different markets with different opportunities for change.

With this assumption, and under a business-as–usual future, this would grow import costs to about $15 billion per annum by 2030 if prices remain at current levels

69 See Jamison 2008. Above n 1.

A reduction of carbon dioxide emissions from passenger transport of approximately 27% might be achieved by 2020 and 78% by 2030.

Figure 12. Estimated net cost of annual fuel imports at today's dollar value or with price inflation through the next five years, followed by falling prices as projected by CSIRO.[71] Each case is shown with and without (business-as-usual) intervention to reduce consumption.



(see Figure 12). The combined impact of the notional portfolio would be to reduce this impost by $13 billion to $2.4 billion per annum (82%) by 2030. Exposure to a hike in net costs might be exacerbated by potentially rising fuel prices related to a combination including growing global demand/competition and diminishing supplies at least at current cost of discovery and exploration. CSIRO[70] has attempted to anticipate how prices may rise in the near future. In one view of the future it assumes that prices may triple in the next few years. If this was to occur, Australia's net cost for the import of oil would amount to over $25 billion per annum. However, as a consequence of such price increases, there will be a move towards technologies such as those described in this paper, that would cause the demand for oil to peak in the middle of this decade and fall dramatically after that, leading to a subsequent fall in prices. This would clearly feedback on the attractiveness of oil exploration and drilling in currently viable high-cost regions and the relative use of oil for purposes other than vehicle fuel. This represents just one potential future and many others may be possible. We have modelled the impact of these price futures with business-as-usual and the full impact of our notional portfolio (see Figure 12).

This Figure shows that the major part of the impact of price rises occurs in the near future and cannot be overcome with the actions proposed within the notional portfolio. It is too late to reduce dependence on these imports sufficiently to have more than a marginal impact in the short term, meaning that motorists are likely to be exposed to significant price rises in the next 2-3 years. However, over the period to 2030, the cost of imports reduces to about $2.4 billion, similar to the cost anticipated with today's prices simply because CSIRO anticipates prices falling almost to current levels by then.

But import savings (economic) are not the only consideration however. Most importantly the portfolio would lead to an independence of global supplies and uncertainties related to security of supply.

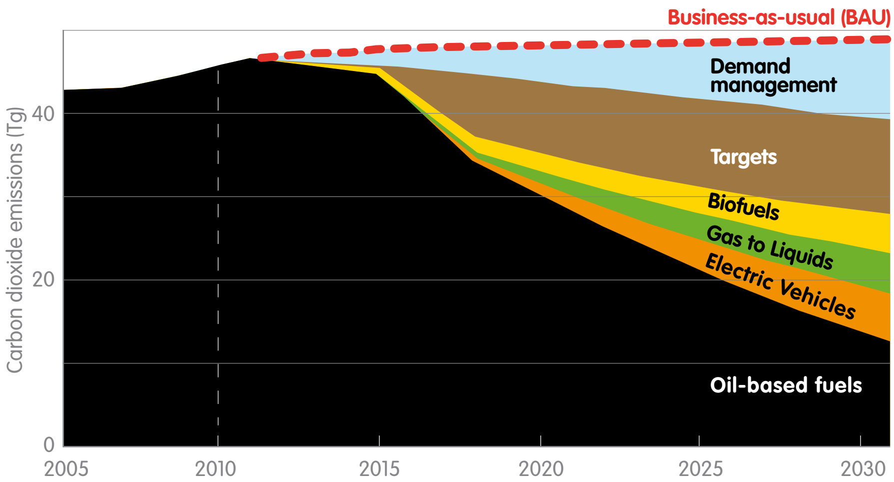
70 CSIRO 2008. *Fuel for Thought: The Future of Transport Fuels: Challenges and Opportunities.* CSIRO, Future Fuels Forum, National Research Flagship, Canberra, p. 44.

71 Ibid.

Carbon dioxide emissions: Figure 13 provides a summary of the estimated contribution to carbon dioxide emissions reductions related to each component of the notional transport energy portfolio. It estimates that a reduction of emissions from transport of approximately 27% might be achieved by 2020 and 78% by 2030. Such reductions would play a significant role in the wider objectives of the national emissions reduction. However, this depends firstly on how efficient gas-to-liquid conversion and biofuel manufacture are in avoiding greenhouse gas emissions. Secondly, it is contingent on the assumption that future development of primary energy production systems such as renewable or low-carbon electricity generation will be provided. Whilst in Figure 13 we show significant reductions in emissions related to biofuels, the discussion in Section 3.2.3 suggests that there remains considerable uncertainty as to the usefulness of biofuels as an emissions reduction methodology, especially when the emissions of nitrous oxide are fully accounted for, and the full sowing-to-pump considerations are made of the energy input and output of the fuels themselves. Similarly, with current technologies, gas-to-liquid conversion (and coal-to-liquid) processes are likely to be accompanied with additional emissions to those that would occur with conventional use of fossil oil.

We consider here the special case of electric cars. Figure 13 suggests that with the notional portfolio, electric cars could reduce carbon dioxide emissions by 2 and 6 Mt CO_2[72] per annum by 2020 and 2030 respectively (4% and 12%). However, this calculation allows for the higher efficiency of electric motors compared with petrol or diesel engines. But it is based on the assumption that the electricity for these

Figure 13: Transport CO_2 emissions. Top curve is the business-as-usual future and successive curves show the contributions to emissions reduction from components of the notional portfolio.



vehicles is provided from zero (or close to zero) emissions sources (nominally wind and solar power), although even these sources are not entirely without some emissions, albeit small. The importance of using renewable electricity is a major point of this document.

Jamison (2008) shows very clearly that there appears to be an extraordinarily strong and new energy in the vehicle manufacturing community toward the development of electric drive vehicles which is perhaps even greater and appears more imminent than indicated in our notional portfolio. Despite these changes within the industry, we see that policy support for the development of electric vehicles needs to be simultaneously coupled to policy for the future production of electricity from non-emitting sources. Without that, this new technology, its opportunities for our manufacturing industry and our independence from imported oil may turn out to be totally incompatible with nationally and internationally agreed futures in terms of emissions reduction. We need inclusive and clear strategies in this regard. The Department of Climate Change[73] estimates

72 1 Mt (million tonnes) = 1 Tg

73 Department of Climate Change. 2009. *National Greenhouse Accounts (NGA) Factors*. Canberra. p. 68. Available at: http://www.climatechange.gov.au/en/climate-change/~/ media/publications/greenhouse-gas/national-greenhouse-factors-june-2009-pdf.ashx.

The last few years have seen a substantial change in attitudes toward electric vehicles.

that the CO_2 emissions (mine-to-power generation) of black and brown coal in Australia are 297 and 383 g CO_2/MJ respectively. The CO_2 emissions associated with oil combustion are 66 g CO_2/MJ. Thus, replacing oil-derived motive energy with black or brown coal-derived energy will lead to massive increases in CO_2 emissions. We appreciate that this comparison is not precise because the mining, processing and transport overheads for oil should be included. Nevertheless, the differences are so large as to clearly illustrate the impost of the use of electricity from these coal sources on the carbon dioxide emissions (see Figure 14).

There are a number of published scenarios of future transport fuel usage that might be compared with this notional portfolio. In particular there are those developed by the Intergovernmental Panel on Climate Change (IPCC; Working Group 3),[74] the International Energy Agency (IEA)[75] and the World Business Council for Sustainable Development (WBCSD).[76]

The IPCC examines the WBCSD scenarios out to 2050. It shows biofuels contributing about 10% (we have 20%) to the reduction of CO_2 equivalent (CO_2e) emissions by 2030 and the combined contribution of hybridisation, diesel, fuel mix and behavioural changes contributing a little over 10%. Our notional portfolio shows 'demand management' changes to contribute to a 20% reduction of emissions by 2030, whereas the WBCSD projections show demand reduction contributing to about a 3% reduction.

The IPCC projection for the light vehicle sector shows (their 'high efficiency' options) a reduction of CO_2 emissions by 27% below BAU by 2030; we have a figure of 38%.

Clearly there are differences between these views of the future. First, the IPCC/WBCSD/IEA analyses are not directed at the multiple goals we are seeking to address. IPCC for example, is interested specifically in CO_2 emissions, and not liquid fuel trade, air quality, or other potential co-benefits of future fuel strategies. Second, these analyses are about the global situation whereas our analysis is about Australia. There is no reason to expect that the options for Australia will reflect some global set of changes.

It is also true that times may have changed views in terms of the imperatives for change (economic, security or emissions), and the technology opportunities. For example the WBCSD projections include the introduction of fuel cell technology towards the end of the decade 2020-2030. We have not done so, based on the impression that what was seen as having potential just a few years ago is now seen as not likely to emerge for at least two decades. On the other hand, we have included the development of electric vehicles in our notional portfolio, something missing from the WBCSD projections. It is possible we might not have included this technology if we had been preparing the portfolio in 2004. The last few years, however, have seen a substantial change in attitudes toward electric vehicles, as outlined in Jamison *The Electric Vehicle Revolution* 2010.

The new IEA analysis shows electric and fuel cell vehicle sales increasing to 14% of the total by 2030 whereas we have electric vehicle sales at 64% of the new car market and having penetrated 33% of the vehicle fleet by this date.

74 Intergovernmental Panel on Climate Change (IPCC) 2007b. Transport and its infrastructure, in *Climate Change 2007, Mitigation of Climate Change.* S.K. Ribeiro and S. Kobayashi (Coordinating Lead Authors), Working Group III of the IPCC Fourth Assessment Report. Eds. B. Metz et al. Cambridge University Press, Chapter 5, p851, or available at: http://www.ipcc.ch/ipccreports/ar4-wg3.htm.

75 International Energy Agency (IEA) 2009. *Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles*, Paris. p52. http://www.iea.org/papers/2009/EV_PHEV_Roadmap.pdf.

76 WBCSD 2004. Mobility 2030: *Meeting the challenges to Sustainability.* Report of the Sustainable Mobility Project World Business Council for Sustainable Development.

Consequently, as a global figure, the IEA suggest that petrol dependency will still be around 40% of the fuel requirement. Whereas our notional portfolio has Australia requiring only 25% of its projected (BAU) fuel demand being oil-based by 2030.

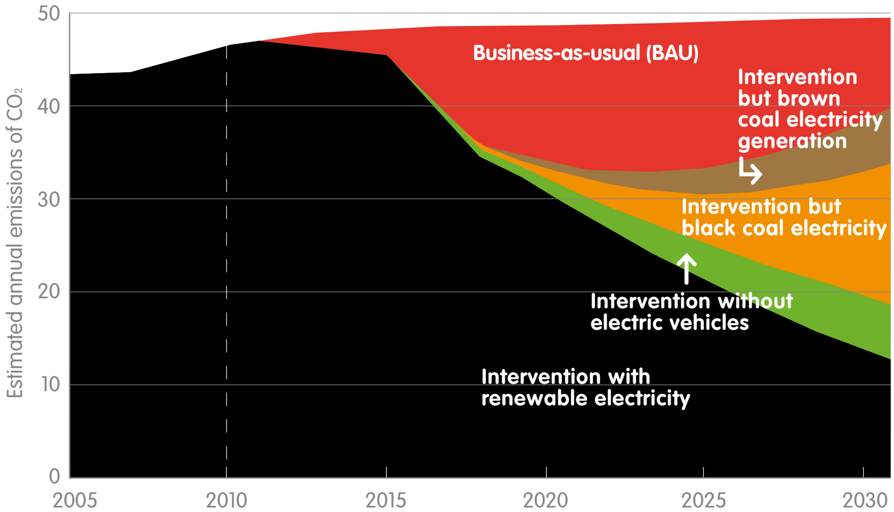
A full analysis of the differences between these views of the future is beyond the scope of this document. However, the differences are likely to result from the issues mentioned above. Most of all, the underpinning multiple imperatives that the Jamison Group see as important stem from Australia's need to reduce its dependence on oil, particularly imported oil.

4.6. Comments about the portfolio approach

The portfolio of actions described above and illustrated in terms of reduced energy demand and imported oil dependency in Figures 10 and 11 can, on the basis of this preliminary study, be regarded as no more than early estimates of the opportunities that exist. Each component of the portfolio includes uncertainties in both the magnitude of change that can be delivered and the time in which that delivery can take place. A more comprehensive study than the one presented in this document might provide greater detail around both these components of uncertainty.

Nevertheless, the portfolio illustrates in the first instance that there appear to be realistic opportunities to address the multiple problems of the ongoing supply of fuels for motor vehicle transport and the reduction of greenhouse gas emissions. It clearly illustrates that any one solution is unlikely to produce the necessary outcomes and that only sets of solutions, albeit complex, sometimes daunting, and from a policy development perspective, difficult, are likely to achieve the required outcomes. We strongly commend the approach and accept the potential for debate and further development of the details contained within the portfolio. The Jamison Group strongly recommends early action to commence the implementation of these measures.

Figure 14: Estimated annual emissions of CO_2 for business-as-usual, with the impact of the notional scenario of interventions, where electric cars are powered by zero-emissions (renewable) sources and where the electricity is provided from conventional black and brown coal power generation.



The Jamison Group is of the view that previous attempts to address these issues, although well meant and, indeed, well informed, lacked a holistic approach and attention to the plethora of issues that realistically need to be addressed in the development of good policy. The wide range of relevant issues that need to be considered in developing sound policy requires independent and holistic review through integrated expertise. It is recognised that the complexity of issues makes sound decision making challenging for governments, who at times are under pressure to provide solutions from narrow interest groups. A review by an independent body of experts may facilitate the balancing of what may appear to be competing demands.

5. Barriers to a transition

Making the leap from the current system to one incorporating a productive and sustainable fuel and technology mix is made difficult by numerous barriers to change. Resistance by individuals and society to change, opposition by those with a vested interest in maintaining the status quo, delays in infrastructure development and the need for political will to enact supportive regulation are all among the hurdles to address.

> The uptake of new technologies, fuel types and/or distribution systems demands the concomitant development of technological capacities to build, install and maintain these systems.

The challenge of delivering the multiple objectives presented here is complex, in part because there exist a range of potential barriers to bring about such a transition. We briefly explore some of these barriers below:

Behavioural

We have already mentioned that to a large extent current issues arising from motor vehicle use and fuel consumption derive from socially developed expectations and attitudes towards mobility. These human conditions are strongly embedded in the cultural and learned psyche of our society; they are underpinned by such things as how we perceive individual freedom and our concept of success. As such they will be difficult to change, particularly in the short term. Social and individual behavioural preferences may greatly influence consumer behaviour and result in such consequences as resistance to the uptake of alternative technologies that appear to conflict with current perceptions concerning safety, comfort, power, performance and prestige – some of which have been well and truly reinforced through decades of advertising. Indeed, this may turn out to be the greatest potential barrier to the uptake of change that is required.

Vested interests

Aside from these society-wide preconceptions, sections of the community have vested interests by virtue of their dependence on the continuation of the status quo with regard to motor vehicle use, technologies and fuels. These include those who explore, mine, refine and distribute conventional oil products; those who build, advertise, manufacture, sell and service conventional motor vehicles; and those who have resources invested in companies that are involved in these processes. The important point here is to offer opportunities for those with vested interests to make the necessary transition. This should proceed at a rate that is cognisant of the demands created by the issues of fuel security and emissions reduction. This requires judgement and does not guarantee that all interests will be satisfactorily or equally satisfied. The expectation is for ongoing resistance to change from some of these areas.

Human training and capacity

The uptake of new technologies, fuel types and/or distribution systems demands the concomitant development of technological capacities to build, install and maintain these systems. For example, motor vehicle mechanics trained in the servicing of conventional internal combustion engines will be required to make a transition to dealing with hybrid, electric drive and alternative fuel systems. The timescales for the introduction of these changes discussed in this paper are short compared with the lifetime cycle – involving education, training and professional career – of the average person. To deliver these changes, special consideration needs to be given to in-service and ongoing training related to the provision of new services and the opportunities for new careers and jobs.

Infrastructure

Each new energy or fuel system can only be useful to the consumer when accompanied by the infrastructure for the refining, processing and delivery of that fuel to the motoring public. Each system will, in itself, be different and require the simultaneous development of delivery infrastructure. Whilst there may be issues concerning the costing of such infrastructure, and who pays for it, there are also issues concerning the rate at which it can be installed to meet demand. These factors may limit the rate of transition from one system to the next.

The taxation system has the potential to significantly enhance or impede the required responses to the issues of fuel security and greenhouse gas emissions.

Agricultural capacity

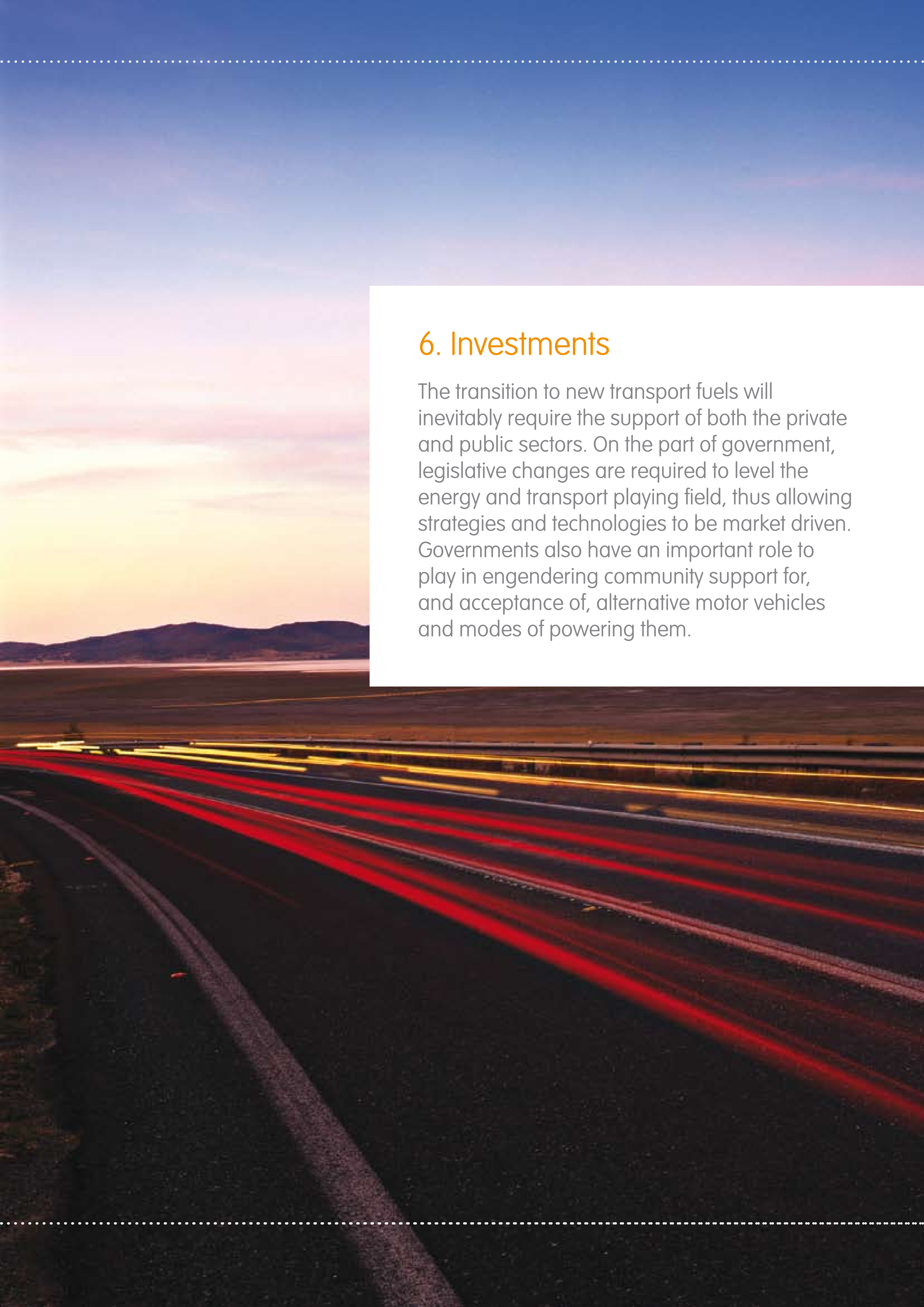
We have discussed the issues concerning the possible transformation of Australia's agricultural sector from one that focuses specifically on food and fibre production for the global market to one in which at least some component of the production system is re-directed to the provision of energy. The capacity of the agricultural sector to make such changes will, as discussed, depend on economic advantages or regulatory interventions that make it attractive to the farmer. There are other constraints related to the rate at which properties can be converted from one form of production to another. These include the co-development of processing facilities, the provision of finance, the experience and technical capacity of the farmer(s) to make the transition, as well as the current stresses on productivity associated with existing climatological conditions. While it appears that agriculture may be exempt from the Carbon Pollution Reduction Scheme, reluctance to make such changes may persist. Nevertheless, to meet our proposed targets of 1 GL by 2020 and 2 GL by 2030, we think that efforts should be made to address these barriers.

Regulation

We have also emphasised above the role of regulation in bringing about change, particularly when the changes are required to address broader community objectives, and at a rate that challenges the existing systems. Regulation is, however, developed within the framework of government systems which themselves have limitations, some of which relate to the election cycle and the difficulty of addressing what are strategic issues. Others relate to the way in which elected politicians cope with extremely complex issues that require a trade-off between a range of alternative outcomes and a range of potential options. The latter can lead to politicians focussing on their responsibility to represent specific interests (sectors, electorates) without due consideration of the broader context, or to their own preconceived and ideological positions. The reality is that these situations exist and they represent a potential barrier to the development of the scenarios articulated in this paper.

Taxation system

The taxation system has the potential to significantly enhance or impede the required responses to the issues of fuel security and greenhouse gas emissions. It is clear that some components of the existing taxation regime work to encourage motor vehicle use and fuel consumption. There needs to be a wide examination of those circumstances where perverse outcomes occurred as a result of taxation regimes that were instigated to deal with problems and potential outcomes from a narrow and out-dated perspective. It is also true that taxation has been used extensively in the past to support the development of particular sectors, or in some cases to prop up sectors/companies in the face of potential political backlash. These circumstances also need to be reviewed as together they may seriously impact on Australia's capacity to respond to these challenges.



6. Investments

The transition to new transport fuels will inevitably require the support of both the private and public sectors. On the part of government, legislative changes are required to level the energy and transport playing field, thus allowing strategies and technologies to be market driven. Governments also have an important role to play in engendering community support for, and acceptance of, alternative motor vehicles and modes of powering them.

The achievement of the reduction of liquid fuel imports (as outlined in this document) can lead to simultaneous and positive outcomes which add to the sustainability of the Australian economy. This may include security against discontinuity of supply, jobs in motor vehicle manufacturing and associated areas, the reduction of greenhouse gas emissions, and a reduction of the impact of motor vehicle emissions on human health. As such, many of the outcomes will deliver economic benefits and may thus be attractive to investment from the private sector. Some outcomes, however, are strategic, in the national interest, and relate to areas in which government responsibilities overlay the market mechanisms.

As a result investments will be required from both the private and public sector to achieve these outcomes. Some of these are outlined in the points below.

Community awareness

The movement towards significant improvements in motor vehicle energy efficiency inevitably requires a combination of the introduction of new fuels and motive technologies, together with changed community acceptance of alternative motor vehicles. Community perception is the single most important driver of motor vehicle selection and purchase. Such perceptions need to reflect more directly the personal and community benefits afforded by both alternative technologies (including hybrid-electric and electric-drive vehicles), alternative fuels (including diesel, biofuels and natural gas), reduced vehicle size and reduced vehicle use (through greater attention to usage patterns and increased alternative transport). However, opportunity and cost are key drivers in consumer behaviour and therefore, governments, together with motor vehicle associations and major transport companies, have a significant role to play in developing this community awareness through the investment of resources in educational and promotional campaigns and through providing incentives to change.

Government procurement

All levels of government are of significant importance in determining the nature of new-car purchases and, ultimately, the resale market. In this regard government procurement policy can be significant in driving the strategic direction of preferred motor vehicle technology, motor vehicle size and fuel econsumption. It is vital to the community interest that governments lead in these directions and it is appropriate for public funds to be used for this purpose.

Domestic manufacturing

Vehicle manufacturing supports a very significant Australian workforce, particularly in the states of South Australia and Victoria. Investments made by governments in support of this sector during the international financial crisis have been, in part, directed at the encouragement of the industry to move towards vehicle manufacture that is likely to be more appropriate for the future. With the implementation of strategic guidelines for the ongoing reductions in motor vehicle fuel consumption, it may be appropriate for further investments in this sector that simultaneously supports the sector and delivers the wider outcomes of such changes as detailed in this document.

Government procurement policy can be significant in driving the strategic direction of preferred motor vehicle technology, motor vehicle size and fuel consumption.

Research

There are several areas in which investments need to be made by both the private and public sectors in relation to the issue of future transport fuels. These include:

Security: We have argued in this document that national security related to the ongoing provision of fuels for transport has been insufficiently addressed from the broader perspectives considered here. Research is required to:

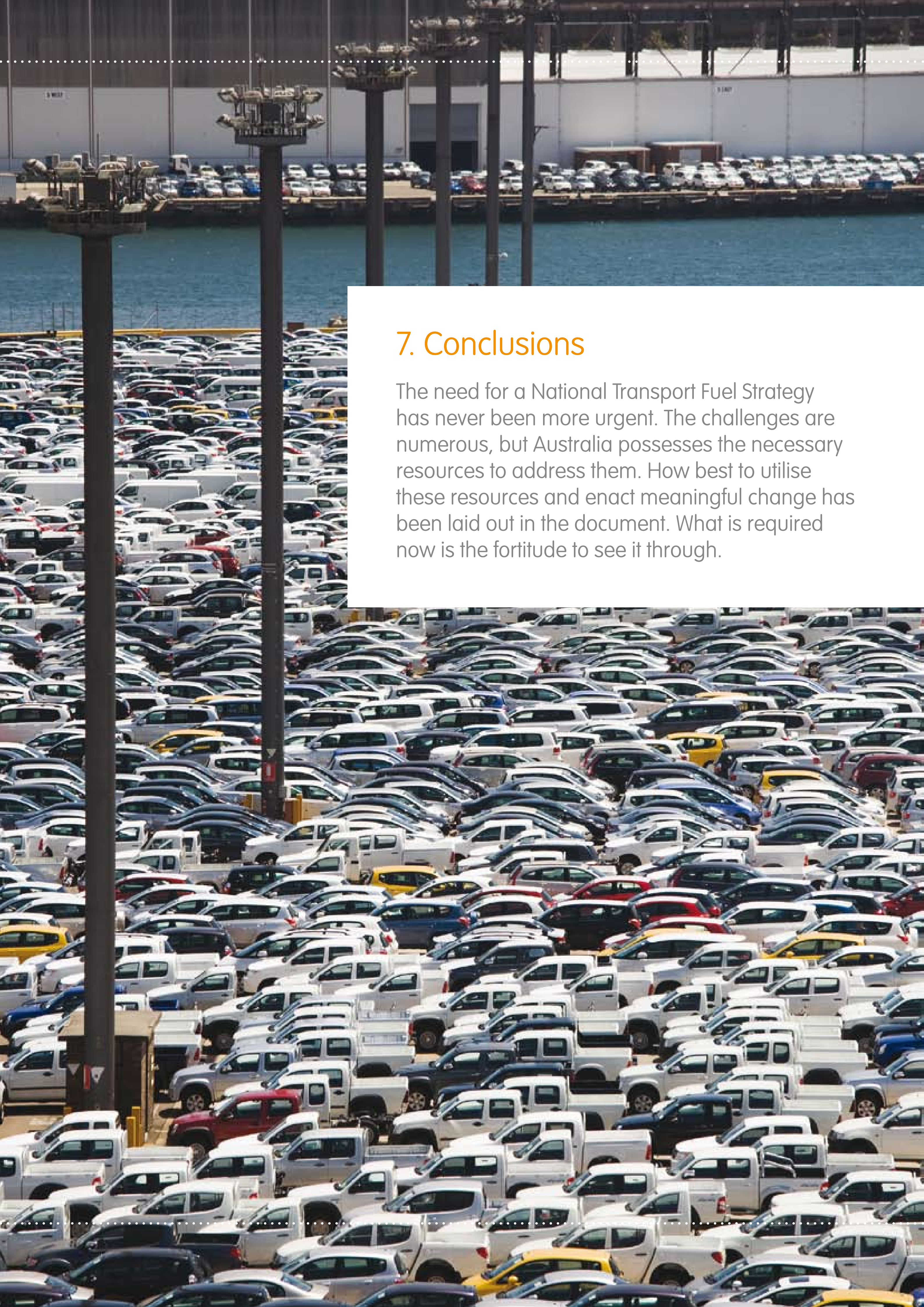
- Better define the vulnerability of the Australian community to dislocations in imported energy resources;
- Rigorously develop a risk assessment associated with such vulnerability; and
- Establish a firm basis for the management of this risk.

Health: More research is required to determine the effect on human health of exposure to very fine particles. Furthermore, we should look to develop an epidemiological basis for assessing impacts of transportation on human health and its social and economic costs. A better understanding of these issues has the potential to drive a strong economic motivation towards the improvement of motor vehicle emissions and regulation concerning particle emissions, an area in which Australia lags its European counterparts.

Scenario development: The scenario development undertaken within this study is, by and large, qualitative and preliminary. To undertake this task more rigorously requires investments in research undertaken by multidisciplinary and interdisciplinary teams of researchers to cover the wide range of societal sectors and aspirational outcomes that have been identified.

Vehicle production strategies: The transitioning of the Australian automotive manufacturing industry and its components-production counterparts to new technologies may require new vehicle production strategies and technologies. There are broad social and economic benefits to public and private sector investment in researching the strategic and technology options required to make such transitions.

Government incentives and regulation: There are current examples of government incentives and regulations that tend to work against the goal of achieving a reduction in liquid fuel demand. These need rigorous examination to determine what changes to these regulatory systems are required to achieve the objective of reducing Australia's need for oil – particularly imported oil. This may be achieved through the current taxation review or separately.



7. Conclusions

The need for a National Transport Fuel Strategy has never been more urgent. The challenges are numerous, but Australia possesses the necessary resources to address them. How best to utilise these resources and enact meaningful change has been laid out in the document. What is required now is the fortitude to see it through.

Efforts to reduce energy demand for motor transport may be through improved infrastructure, public awareness and changed attitudes to public transport.

Australia faces severe simultaneous challenges with respect to the provision of fuels for future motor vehicle transport. These include: increased demand, diminishing national oil production, global competition for oil, potentially higher prices, balance of trade/payments, threats to security of supply, public health and limitations to greenhouse gas emissions.

In this document, preliminary attempts are made to evaluate a set of options, a portfolio, for conjointly meeting these challenges specifically for motor car usage. We stress that this scenario is notional: one set of ideas as to how these challenges may be addressed. The Jamison Group argues that such a holistic approach is required to maintain resilience in the face of the uncertainty concerning the potential contribution over time of each of the available options and that further work would help to better narrow these uncertainties. Components of the notional portfolio for motor cars include:

Reductions of demand

Efforts to reduce energy demand for motor transport below current business-as-usual projections may be through improved infrastructure, public awareness and changed attitudes to public transport, walking, bicycling, and personal attention to more selective motor vehicle use, improved transport flows and town planning. Such changes may result from public education/awareness programs and comprehensive and strategic planning (communication, town planning, population growth) across government departments. These actions may deliver reductions in oil dependency and greenhouse gas emissions below business-as-usual in 2020 by 10% (equivalent to 74 PJ of energy, 2 GL of liquid fuel and 5 Mt CO_2 of emissions annually) and in 2030 by 20% (150 PJ, 4 GL and 10 Mt CO_2) respectively.

Interventions

Achieving these outcomes will depend on state and federal government intervention to both set the environment for market adjustments and to promote future investments and rapid change, including:

- The setting of mandatory motor vehicle fuel consumption standards for new cars sold into the Australian market. In the first instance all manufacturers may be required to have the average of their new passenger car fleet sales meet a fuel consumption target of equal to or less than 130 g CO_2/km by 2015, consistent with the consumption standards now established in the European Union. A 95 g CO_2/km fuel consumption fleet average standard could be set for new vehicles sold from 2020. In both cases phasing-in targets are suggested over the preceding years;
- Removal of taxation relief for businesses that have the potential to promote perverse outcomes related to inappropriate vehicle type and size and their greater use (kilometres driven), and the diesel excise rebate;
- Establishment of responsible car use and driving through public promotion campaigns;
- Provision of alternatives such as improved public transport and public transport access. Funding of new railway lines, railway rolling stock, train and bus drivers, and cycleways;
- Support for research and development to assist:
  - Consideration of the whole-of-life energy demand of vehicles
  - Holistically assessed biofuel and other alternative fuel options
  - Electric car introduction (in conjunction with renewable energy development and upgrading the grid)
  - Gas vehicle efficiency improvements in new vehicles and retrofits.

Such interventions need to be seen in the wider context of community benefit across all of the challenges identified above, justified in both immediate and strategic terms, and cognisant that there will inevitably be structural changes associated with these necessities.

Achieving desired outcomes will depend on state and federal government intervention to both set the environment for market adjustments and to promote future investments and rapid change.

Technology transfer

It is anticipated that the fuel consumption targets would be met by manufacturers through a range of complementary actions including the reduction of size and mass, the uptake of hybrid and diesel technologies, active encouragement of fleet retrofit to natural gas and LPG, along with strategies for the introduction of electric-drive vehicles. Electric vehicle introduction over the next two decades in this notional scenario reduces oil demand by 2020 by 5%, but has the capacity to reduce demand by 12% by 2030. Such a transition would significantly reduce greenhouse gas emissions (7 Mt CO_2 per annum), if the electric power comes from renewable or non-emitting sources. Thus, electric vehicle futures need to be considered urgently and holistically within a wider national strategy for energy supply and utilisation.

Introduction of liquid fuel substitutes

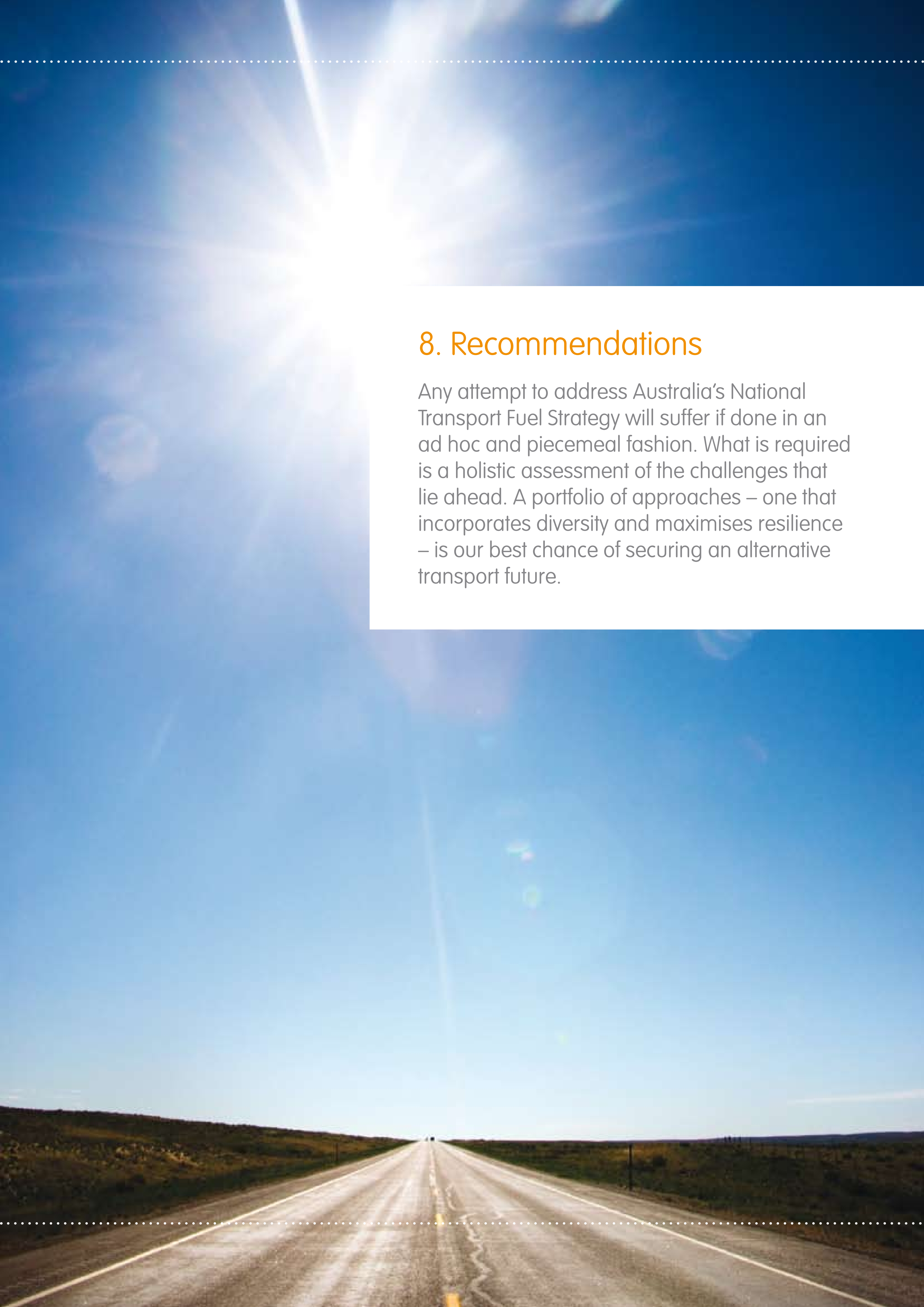
Two approaches considered in the notional portfolio include the development of a biofuels industry that captures biomass through environmentally acceptable and economically sensible processes, and the conversion of natural gas into liquid fuels. We estimate for our notional scenario that these measures might reduce the oil dependence by 5% (36 PJ, 1 GL per annum) and 3% respectively by 2020 and 10% (72 PJ, 2 GL) each by 2030. This notional scenario would reduce greenhouse gas emissions only if the production and processing of the biofuels, or the conversion of gases to liquids, is without emissions. This is less likely and the current reality is that fuels provided by gas-to-liquid conversion will contribute similar greenhouse gas emissions as oil-derived fuels.

We have not examined the important and growing contribution to liquid fuel demand made by the commercial and industrial transport sector (trucks and light delivery vehicles). We assume at this stage that a similar set of actions could reduce imported oil requirements and greenhouse gas emissions by similar amounts as for motor cars, but recognise that these are different markets with different opportunities for change. We also suggest that expanding aviation demand for liquid fuels may well compete for liquid fuels substitutes as the options for aviation are less varied than for the motor vehicle sectors.

Recognising the uncertainties and the combined opportunities, we expect that energy demand from imported liquid fuels for all transport needs could be reduced from expected business-as-usual projections by 50% and 84% by 2020 and 2030 respectively (see Figure 11). This corresponds to a reduction of the annual cost of imports in today's dollars of approximately $7 billion and $13 billion by 2020 and 2030 respectively and a concomitant improvement in terms of lowered vulnerability to price rises or disruption of imported fuel supplies.

It is also consistent with a reduction of greenhouse gas emissions of 32% and 72% from this sector by 2020 and 2030 respectively. However, this latter outcome depends on exactly how successful gas-to-liquid conversion and biofuel manufacture are in avoiding greenhouse gas emissions and this in turn, amongst other things, is contingent on future development of primary energy production systems such as renewable or low-carbon electricity generation.

The options in this portfolio of actions combine to project an overall demand reduction from BAU oil by 2030 of about 560 PJ per annum (-75%) to 190 PJ per annum.



8. Recommendations

Any attempt to address Australia's National Transport Fuel Strategy will suffer if done in an ad hoc and piecemeal fashion. What is required is a holistic assessment of the challenges that lie ahead. A portfolio of approaches – one that incorporates diversity and maximises resilience – is our best chance of securing an alternative transport future.

Options for the future are diverse and require utilisation of a portfolio of approaches that builds in diversity and maximises resilience.

1. The Australian Government should move swiftly to adopt a holistic approach to establishing a national transport fuels strategy that simultaneously addresses:

- Anticipated increased demand related to population and economic growth and community aspirations;
- Diminishing national oil production;
- Global competition for oil;
- Potentially higher prices in the face of diminishing resources and rising international demand;
- Balance of trade/payments;
- Threats to security of supply with low probability but very high impact;
- Public health related issues to vehicle emissions;
- Limitations to greenhouse gas emissions;
- Co-benefits and possible conflicts between the future of the wider energy sector and industries in Australia.

2. A strategy should be built around the understanding that options for the future are diverse, but surrounded with ongoing uncertainty and thus require utilisation of a portfolio of approaches that builds in diversity and maximises resilience.

3. The first key steps in this approach should be:

- *Demand reduction*: The establishment of programs to reduce private and commercial transport demand through promoting awareness of opportunities to reduce demand such as improvement in trip selection and general usage. Reduced population growth and the removal of subsidies to car use would also assist demand reduction;
- *Alternative transport modes*: The promotion and improvement of public transport and alternative modes of transport and significant new investment through town planning and new public facilities that lower the impact of population growth on future demand;
- *New car fuel consumption standards*: The setting of new fuel consumption and emissions targets for all new motor vehicles sold into the Australian market consistent with the European Union standards. The recommendation is that the 130 g CO_2/km target be phased in beginning in 2014 and reaching 100% of the fleet average of each manufacturer's sales by 2015 (two years later than in the European Union) and 95 g CO_2/km phased in from 2018 to 100% by 2020;
- *Alternative fuels*: The promotion of alternative fuels from biomass and from gas-to-liquid or coal-to-liquid conversion where this is clearly consistent with the broader objectives of simultaneous provision of liquid fuels, the lowering of greenhouse gas emissions and economically justifiable costs free of subsidies other than those required for the establishment of these new industries;
- *Electric cars*: The promotion of the development and uptake of electric vehicles where this is clearly consistent with the broader objectives of simultaneous provision of liquid fuels, the lowering of greenhouse gas emissions and economically justifiable costs free of subsidies other than those required for the establishment of these new industries.

4. The support of holistic research related to the following key areas of uncertainty:

- *Security*: To better define the vulnerability of the Australian community to dislocations in imported energy resources, to rigorously develop a risk assessment associated with such vulnerability and recommend a basis for the management of this risk;
- *Health*: To assess the human health exposure resulting from very fine particles and the development of an epidemiological basis for assessing the impacts of transportation on human health and its social and economic costs;
- *Scenario development*: The scenario development undertaken within this study is, by and large, qualitative and preliminary and needs to be substantially complemented by investments in research. It should also be undertaken by holistic teams of researchers to cover a wide range of societal sectors and aspirational outcomes that have been identified and to include:
  - More rigorous economic analyses of options;
  - Inclusion of socio-political aspects of demand, propensity for change and employment opportunities;
  - Inclusion of the haulage and freight components of the transport sector;
  - Inclusion of aviation fuels, demand and options;
  - Integration with other energy supply and demand sectors;
- *Vehicle-production strategies*: Research into the support necessary for new vehicle production strategies and technologies to transition the Australian automotive manufacturing industry and its components-production counterparts;
- *Government incentives and regulation*: Research to identify current shortcomings of government incentives and taxation processes that work against the delivery of holistic outcomes for the Australian community and identifies new incentives and taxation regimens to enhance these outcomes.

Roadmap

The future fuelling of Australia's motor vehicle fleet remains uncertain. This roadmap is designed to provide resilience in the face of these uncertainties and to maximise the delivery of multiple outcomes in terms of security of supply, balance of trade, human health improvement and greenhouse gas emissions reductions. It is recognised that no single action or set of actions will provide for all of the desired improvements so a portfolio approach is the best way forward as outlined in the Roadmap overleaf.

Roadmap for the provision of future motor vehicle fuel in Australia, showing a multiple-pronged or holistic approach.

	Roadmap step			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2025	2030
1	Construct a new national transport fuel strategy	Inclusive of multiple objectives, diverse options and consistency with a revised national energy strategy		Strategy development		On-going reassessment and revision										
2	Demand management – creating choices to reduce fuel use and increase consumer and fleet uptake of new technologies	Awareness and behavioural change (% reduction from Business-as-usual – BAU)			1	2	3	4	5	6	7	8	9	10	15	20
				Public awareness campaigns and new behavioural paradigms												
		Improved public transport and non-fossil-fuelled transport		Strategic planning and infrastructure investment, providing improved accessibility and travel times; • Promotion of new infrastructure for public transport, cycling and walking • In particular, light rail and fast metros for urban centres and sub-centres • Fast heavy rail for linking urban centre and sub-centres and for intercity travel • Mixed-mode urban – plan for multiple transportation modes, in particular, support walking and cycling options												
		Haulage options		Strategy for balance between rail, air, road freight with greater rail contribution												
3	Introduce compulsory fuel consumption standards for all new cars/ vehicles	EU 130 g CO_2/km (% sales meeting target)		Announce intent				65	100	100	100					
		EU 95 g CO_2/km (% of sales meeting target)		Establish long term targets								75	85	95	100	
		Green Car Fund to rebuild Australia's automotive industry		Enhanced targeted investment			New Australian models meeting EU consumption targets					Australian manufactures globally demanded low-emissions vehicles				
4	Tax and other incentives, legislative reform to stimulate consumer and fleet demand for vehicles running on alternative fuels or propulsion systems e.g. electric vehicles	Use the Emissions Trading Scheme to build an alternative fuels and technology industry		Transport sector strategy for 2009 emissions targets				Transport sector challenged by unfolding higher emissions reductions targets						Targets met		
		Grow new alternate fuels and technologies and supporting industries e.g. smart grid and batteries	Biofuels (% 2010 fuel)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	10		
				Economic/social analysis				National/regional strategies and incentives						Mature industry		
			Natural gas	New vehicle and retrofit options for transition to a low carbon future of motor vehicles												
			Gas to liquids (% 2010 fuel)	Pilot			Operational			0.7	1.3	2.0	2.7	3.3	6.7	10
			Electric cars (% 2020 fuel)	Support manufacturers transition					0	1	1	3	3	4	8	12
		Build infrastructure needed		Set a strategy			Encourage private sector investment									
		Wind back subsidies that reinforce oil dependence		Set a strategy			Phased out subsidies			No subsidies – perverse taxations and incentives removed and co-benefits of decarbonisation rewarded						
		State Governments reform tax and tariffs		Lower registration charges for low-consumption vehicles e.g. hybrids and electric vehicles												
		Mandate the production of alternative fuels and renewable energy to meet targets		Set a strategy			Commence phasing in targets			Targets set and met						
5	Compulsory CO, NO_x, HC and particulate emissions standards					Euro V			Euro VI							
6	Research and training	Immediate and concurrent research investment relating to:		• Fuel security issues • Support and development of vehicle production strategies • Role and opportunities for government incentives and regulation • Defining health impact of emerging emissions • Use scenario development as a means of investigating multiple outcome policy development to build resilience • Training which enables skills transfer to support new technologies												

Appendices

Appendix 1: Fuel-production technologies

A1.1. Gas-to-liquid fuels (GTL) technologies

Production of liquid fuels from natural gas involves conversion by way of chemical processing. Typically, GTL processes are used to make methanol, dimethyl ether (DME), diesel or gasoline, all of which can be used as transport fuels or blended into oil-derived fuels.

A methanol-to-gasoline plant was commissioned in New Zealand in 1985 with a refining capacity of 14,500 barrels per day (approx. 31 PJ per annum).[77] This plant no longer produces gasoline due to its lack of competitiveness with imported crude and refined product as well as a diminishing local reserve of natural gas. Consideration has been given to starting up gasoline production once more. This decision will depend on several factors, one of which is the world price of crude oil. Others include the cost of recommissioning the gasoline conversion unit and the guarantee of supply of the natural gas feedstock. The plant currently produces methanol.

The process used commercially for GTL technologies involves two steps (see Figure 8). The first involves production of syngas or synthesis gas, a mixture of carbon monoxide and hydrogen. The two major players in this area use different technologies for syngas generation. One uses a combination of partial oxidation and reforming and the other uses reforming and combustion. Both employ a process known as Fischer Tropsch Synthesis (FTS) to convert syngas to synfuels. Each has proprietary reactor technology for this conversion process. These different technologies give slightly different ranges of products.

Work in Australia is focusing on process improvement and downsizing as well as novel processes with the intention of lowering energy requirements for GTL processes as well as capital costs at the same time as improving process efficiencies. One research effort is investigating using waste heat from syngas generation to generate electricity that can be used to drive other processing and plant equipment or can be exported to the grid.[78] The use of this waste heat on a small-scale methanol facility such as the Coogee plant in Laverton, Victoria, could see as much as 5 MW of electricity generated. This is only a tiny fraction of the electricity generated in Australia each year (approximately 0.001%) but these new technologies are a pointer to the future where co-generation and use of waste heat in engineering processes are commonplace rather than exceptional. The equivalent amount of electricity generated from Victorian brown coal would emit 60 kt of CO_2e per year. In dollar terms, generating 5 kW of electricity by the co-generation process above compared to generating the same amount of power from brown coal would save the producer $5.6M per annum (assumptions: carbon price of $20 per tonne CO_2e and an electricity cost of $0.1/kWh).

A1.2. Biomass-to-liquid fuels (BTL) and other technologies

Bioethanol and biodiesel are currently produced around the world as primary fuels (Brazil) or as additives to fuel (Australia, Europe, USA, others). Bioethanol production worldwide is in the order of 50 GL per year (1200 PJ per year) with Brazil and USA leading production. Brazil makes its bioethanol from the fermentation of sugar and USA from corn.

The technical feasibility of production of bioethanol on an industrial scale is not in question. However, the commercial realities of fuels from biological feedstocks, particularly first-generation biomass feedstocks (those that are derived from food crops) are still in question.

Biologically derived feedstocks can also be processed by gasification to yield syngas (carbon monoxide and hydrogen). The syngas is converted to liquids via FTS. This process is similar to the practised processes in GTL synthesis in that it uses the same second step to convert syngas to fuels.

77 Sunggyu Lee (ed), James G. Speight (ed), Sudarshan K. Loyalka (ed) HAFT 2007. *Handbook of Alternative Fuel Technologies.*

78 Trimm, D.L., Burke, N.R. *et al.* 2006. *Production of synthesis gas involves contacting mixture of hydrocarbon fuel and oxidizing gas with a catalyst coated on blades of turbine to produce heated synthesis gas, and passing the heated gas through turbine.* Commonwealth Scientific and Industrial Science Organisation. WO2006/066335 A1.

A1.3. Liquefied natural gas

LNG is an established technology in competition with GTL in that the same gas resource can be used to make LNG or GTL products. As with GTL, LNG is most economically attractive when gas prices are cheap and when used in larger-scale facilities. Normally, LNG is not used as a transport fuel. It could be used in theory, but it would require re-gasification facilities (to convert the liquid to gas) or appropriate storage and the product (natural gas) would require vehicle modification. In 2006 Australia produced 1950 PJ of natural gas.[79] This is equivalent to approximately 23% of Australia's oil usage. The costs of such conversion are unclear. LNG is traded on the world market and considered by producers to be a better investment than GTL, as is evident by the recent proposals for LNG facilities in Queensland to utilise coal seam gas reserves. The reason for this could be that the technology is more mature than GTL and infrastructure costs are generally lower. The comparative economics with respect to LNG/GTL are expected to change once operational experience with the large GTL facilities has been gained.

A1.4. Potential contribution to energy demands

Natural gas is already making a significant contribution to energy production and demand in Australia, but for transport the contribution is small, as shown above (approximately 3%).[80]

Given that the majority of Australia's gas reserves are remote and/or not considered large enough to warrant significant capital investment, priority should be given to developing technologies that require less capital investment (i.e. smaller footprint plants that can be relocated as necessary). Energy efficiencies of GTL processes also need to be addressed. These can be improved through modification of established technologies and demonstration of novel technologies. Use of waste heat, lower temperature processes, more efficient and stable catalytic materials and processes with improved selectivities to the desired products will all enhance the commercial viability of GTL processes and could ultimately unlock many of Australia's stranded gas reserves, thereby reducing the requirements for imported transport fuels.

A1.5. Potential contribution to greenhouse gas emissions reduction

Conversion of woody biomass to syngas and then to liquid products has been shown to release fewer greenhouse gas emissions than gas, coal or oil-based (crude, plant or animal) alternatives,[81] although this conclusion is highly dependent on a range of boundary conditions used to define the full life cycle (see Appendix 3).

Greenhouse gas emissions associated with GTL fuels are similar or slightly higher than those derived from crude oil (+/- 20%).[82,83,84]

A GTL capability that would make a significant contribution to Australia's transport fuel requirements would take up to 10 years to establish. Its success would be assisted by government policy and may even require favourable government policy in order to succeed in the initial stages. Once established, GTL could contribute 20% or more to Australia's transport fuel requirements.

As mentioned previously, LNG and natural gas production already makes up a significant portion of Australia's energy production. Production has the potential to increase given the abundance of local reserves. As with GTL the reserves are often small, remote or stranded. Investment in distribution infrastructure to allow wider access to natural gas as a transport fuel is required. On-board storage would also need to be considered given the decreased range of natural gas vehicles. Research is being conducted by automotive companies and research institutions into design of longer-range CNG fuel tanks for vehicles to overcome this problem. This, combined with appropriately located refilling stations could see natural gas contributing significantly to Australia's transport fuel requirements.

We have not specifically included the use of LNG or CNG as part of the portfolio, but rather assumed that, in part, in order to achieve future emissions-reduction standards, some manufacturers may choose to use such fuels to meet the suggested targets (see below). This may need to be realised not only through new motor vehicle technologies, but also through governmental support of infrastructure and incentives to bring about these transitions.

In this analysis we have excluded any consideration of aviation fuels, a small yet rapidly growing component of total transport fuel usage. Such an examination is needed and is of special relevance to Australia given its geographic isolation.

79 See EnergyQuest 2009. Above n 34, p. 68.

80 See ABS 2008. Above n 30.

81 See Kalnes *et al.* 2009. Above n 37.

82 Alliance for Synthetic Fuels in Europe 2007. *ASFE position paper: Emissions from Synthetic Fuels*; Available at: http://www.synthetic-fuels.org/documents/20070221124048_ASFE%20Position%20Paper%20on%20Deployment.pdf.

83 See CSIRO 2008. Above n 70.

84 See Jaramillo *et al.* 2008. Above n 40.

Appendix 2: Technology implications for distribution and use – LNG and CNG

Natural gas (primarily comprising methane, CH_4) can be used as a transport fuel in much the same way as oil, the differences being mainly in the means of distribution and containment. After extraction from the well, the gas is subjected to extensive processing to remove almost all materials other than methane. The by-products of that processing include ethane, propane, butanes, pentanes and higher molecular weight hydrocarbons, elemental sulphur, and sometimes helium and nitrogen. After processing, distribution is normally by pipeline or by condensing to liquid form known as Liquefied Natural Gas (LNG). Internal combustion engines can be operated on methane gas with minor modification. Natural gas can be converted to a liquid fuel very similar to petrol in a process described generically as Gas-to-Liquids (GTL). At present the process is of marginal economic feasibility.

However, since modifications involve the engine management system, best results are obtained if the engine is designed from the outset to run on gas or a mixture of liquid and gaseous fuel.

Natural gas is widely claimed to be environmentally better than oil in terms of carbon dioxide emitted. However, fugitive tailpipe methane emissions and emissions during the processing of the gas result in carbon dioxide benefits at the tailpipe being lost in comparison to vehicles powered by oil-derived fuels.[85]

The state of development: Around the world there are many fleets of buses and other depot-base vehicles operating on natural gas with the largest fleets in Argentina, Brazil, Pakistan, Italy, India and China. In the United States several city municipalities have adopted natural gas fleets but there has not been a national program in Australia to encourage wider adoption. Australia has very few trucks (a few hundred) using natural gas and a very small number of cars.

Australia is one of very few countries with country-wide availability (3,200 outlets) of liquefied petroleum gas (LPG) but very few outlets for natural gas for cars and trucks, which probably explains why Australia has been slow to take up natural gas as a transport fuel. LPG is used in almost all taxi cabs in Australia and there are government incentives to purchase or modify cars to use LPG. There are no such incentives to use natural gas.

With more than 7 million cars overseas using natural gas, the technology is well developed and could be used widely in Australia if the gas was more readily available.

Natural gas storage tanks are larger than petrol or diesel fuel tanks for the same range and this is an issue for car designers. However, for trucks it is less of an issue. For depot-based vehicles such as city buses and garbage collection trucks, natural gas can be an attractive alternative fuel.

Line-haul trucking companies are taking advantage of the lower operating cost opportunities offered by natural gas. Moderate capital outlay for the plant to freeze gas that has been drawn from city pipeline supplies results in early pay-back for companies operating fleets of point-to-point line-haul heavy transport. Australia does not have a diesel engine manufacturing industry but overseas engine makers offer a range of mixed-fuel engines specially tuned for maximum fuel efficiency. The engines use both diesel oil and natural gas according to operating conditions, using about 85% of natural gas to 15% of diesel fuel under ideal operating conditions.

Viability of the equipment and procedures involved in operating numbers of vehicles on natural gas has been proven in the Australian Direct Injection Natural Gas Demonstration Project from October 2007 through March 2008. The project was supported with funding from the Australian Government through the Australian Greenhouse Office and involved three major trucking operators in Perth and

85 Ally, J. and Prior, T. 2006. *Life Cycle Assessment of the Diesel, Natural Gas, and Hydrogen Bus Transportation Systems in Western Australia.* Available at: http://www.dpi.wa.gov.au/mediaFiles/alt_confjamieally.pdf.

Melbourne. Loads of between 30 and 100 tonnes over distances between 300 km and 800 km and a variety of commodities such as crude oil, refrigerated goods and milk products were trialled. Sufficient numbers of passenger vehicles are in operation overseas to obviate any need for further testing of the technologies in Australia.

A2.1. Technology strengths and challenges

Strengths: Natural gas offers an important strategic advantage to Australia as a transport fuel. Australia has an abundance of natural gas whereas oil reserves are diminishing. As world demand for oil outpaces supply, oil is likely to become increasingly expensive and could even become difficult to obtain because other oil-dependent nations have been more aggressive in securing long-term supplies.

Most of Australia's natural gas reserves are located off the north-west coast of the continent, whereas most of the potential demand is in the south-east. Production from the western gas fields is exported in special-purpose LNG ships to Korea and Japan and, in future, to China. Using gas from the western gas fields in the populous south-east of the continent would necessitate new infrastructure to offload and store bulk LNG. In the face of potential world scarcity of oil, Australia would benefit from a plan to develop large-scale LNG handling facilities in major ports.

Natural gas used in engines designed or modified for optimal use of the fuel offer reduced emissions and improved air quality. This is especially important in cities or in congested areas because particulates are increasingly identified as a substantial health hazard in concentrations found in typical city environments. The advantage is greatest in comparison with diesel fuel because of the much higher particulates produced in diesel oil combustion, but is also important in comparison with petrol. Some emissions, however, namely methane and carbon dioxide emissions during natural gas processing, are higher than those for vehicles using oil-derived fuels.

Challenges: Shipping LNG from the north-west of Australia to the south-east involves distances almost as great as the distances to Korea and Japan. The existing export routes use facilities that allow maximum use of the devoted vessels. If gas is to be shipped to Australian ports in the south-east, there would need to be sufficient market to take regular loads. Until that point is reached, LNG supplies will be dependent on local pipelines, which could result in pressure drops that cause supply disruption or, alternatively, require new investment in the pipeline distribution system. This dilemma is unlikely to be resolved by the market, implying that a national plan is needed.

For natural gas to become a widely used transport fuel for cars would require widespread availability through a network of retail outlets similar to the network for LPG. The trucking industry, on the other hand, could more easily set up the smaller number of refuelling stations required to support their fleets.

Modifications would be required in order that existing vehicles could use compressed natural gas (CNG). These modifications would involve the engine management system, therefore best results are obtained if the engine is designed from the outset to run on gas or a mixture of liquid and gaseous fuel. With more than 7 million cars overseas using natural gas, the technology is well developed and could be used widely in Australia if the gas was more readily available.

Australia does not have a diesel engine manufacturing industry but overseas engine makers offer a range of mixed-fuel engines specially tuned for maximum fuel efficiency and optimum emissions. The engines use both diesel and natural gas according to operating conditions, using about 85% of natural gas to 15% of diesel fuel.

Priorities for further development and demonstration: The LPG industry in Australia has until recently seen natural gas as a competitor but more recently both interests have recognised that both fuels will be needed in the event of fuel scarcity. This closer cooperation between alternative fuel interests is to be encouraged.

The economic attractiveness of LNG as a fuel for some trucking operations will likely ensure expansion of the numbers of LNG trucks in the Australian fleet. The extent to which this growth places stress on domestic and manufacturing industry needs will need to be planned and managed.

For Australia to gain maximum benefit from its reserves of natural gas, planning for distribution will be imperative because, in the absence of a plan, car makers will not market gas vehicles in Australia. Without a rising number of gas-operated vehicles, investment in retail distribution of the fuel is unlikely.

The Australian dilemma of national abundance of the resource but an inability to distribute highlights the need for a different approach. As cars developed over the past century, more special-purpose variants became available and yet consumers have come to expect that vehicles can be operated anywhere within the continent. This may no longer be a realistic expectation because, as alternatives replace oil, it may be necessary to recognise the regional nature of some of the alternatives. If gas is readily available in one region but difficult to distribute in another, it may be rational to sell gas-capable vehicles in that region, with consumers recognising that their vehicle amenity would be limited to that region.

This dilemma will apply with other alternative fuels. Biofuels may be feasible in certain regions, but it does not make sense to transport biofuel around the continent to ensure an arbitrary mix of biofuel to mineral fuel. Electric vehicles, limited in range, will be ideal for cities because of the high incidence of short journeys in congested conditions but would be less suitable for long journeys. Transport fuel plans are needed that recognise the individual benefits and disadvantages of each alternative fuel.

Appendix 3. European CO_2 emissions from light-duty vehicles

On April 23, 2009, the European Parliament and Council "set emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles".[86] Key components of the new standards include:

Limited-value curves: The fleet average to be achieved by all new cars registered in the European Union is to be 130 g CO_2/km from 2015. The limited value curves imply that heavier cars are allowed higher emissions than light cars but that the overall fleet average must be preserved. This applies also to individual manufacturers who themselves must demonstrate that the average emissions of all new cars registered in the Community – for which they are responsible – do not exceed the average of the emissions target.

Phasing in of requirements: In 2012, 65% of each manufacturer's newly registered cars must comply, on average, with the limited-value curves set by the legislation. This will rise to 75% in 2013, 80% in 2014 and 100% from 2015 onwards, in order to allow a transition period. A target of 95 g CO_2/km is set for 2020, with the phasing details yet to be decided.

Penalties: If the average CO_2 emissions of a manufacturer's fleet exceed its limited value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 of the first g CO_2/km in excess of the limit, €15 for the second g CO_2/km, €25 for the third g CO_2/km and €95 for each subsequent g CO_2/km. From 2019, the first g CO_2/km in excess of the limit will cost €95. Again this allows for a transition period.

Table A3. Approximate fuel consumption and CO_2 emissions of popular Australian cars.

Size	Model	Consumption (L/100 km)[1]	CO_2 emissions (g CO_2/km)[2]
Small car	Toyota Yaris	6.0	141
	Ford Fiesta Econetic	3.7	98
Medium car	Toyota Prius	3.9	89
Large car	Holden Commodore	10.8	305
Off road	Ford Territory	12.2	340
	Toyota LandCruiser	14.5	409

1 Based on consumption figures in the Department of Climate Change Green Vehicle Guide. http://www.greenvehicleguide.gov.au/GVGPublicUI/StaticContent/pop_search_v2.aspx.

2 Based on approximate conversion of 282 g CO_2/km being equivalent to a consumption of 10 L/100 km.

Eco-innovations: Test procedures used for vehicle approval are outdated so that certain innovative technologies may not be able to demonstrate their CO_2-reducing capacity under the current approval test. As an interim procedure, until the test procedure is reviewed by 2014, manufacturers can be granted a maximum of 7 g CO_2/km of emissions credits on average for their fleet if they equip vehicles with innovative technologies based on independently verified data.

The standard of 130 g CO_2/km is compared with current emissions of selected Australian vehicles in Table A3. It shows that, of the vehicles listed, only the Ford Fiesta Econetic and Toyota Prius would meet these new European emissions standards. Only a small number of the cars listed in the Green Vehicle Guide are under 130 g CO_2/km. According to the manufacturer's specifications, the Volkswagen Golf TDi (diesel) manual version achieves 130 g CO_2/km, but it is not listed on the Green Vehicle Guide website yet.

The larger vehicles exceed these standards by 2-3 times.

86 See Regulation EC No 443/2009 above n 64.

Appendix 4. Construction of a scenario for motor vehicle fuel consumption

We start with the assumption that energy demand for car transportation (E(t) in PJ) will grow, primarily in response to population growth (at a little less than 2% per annum), through to 2020 in accordance with the projections of BTRE[87] and linearly extrapolated through to 2030. This will be considered the business-as-usual case (see Table A5.1).

It is important to note that these projections are based on wider government decisions concerning immigration, but we have not considered the direct consequences of changes in immigration policy. We simply comment that decisions concerning immigration should have, as part of their rationale, the range of challenges being considered in this document. Should population growth proceed through the next decades at the rate experienced in the past year (~2.3% per annum), then demand would grow by more than 10% above the business-as-usual scenario.

We convert the annual energy demand to liquid fuel volumes, (υ in GL) assuming that, as current fuel consumption is dominated by petrol and that the energy content of petrol and diesel are similar (respectively, 35 and 43 MJ/L), then,

$$\upsilon(t) = E(t)/35 \qquad 10^9 \times L \qquad A1.$$

We use the national fleet fuel consumption of 11.23 L/100 km (ATC 2008) in 2005 and the new car fuel consumption estimate $\varepsilon_n(t)$ of BTRE (2005) from 2004 through to 2025 and extrapolated to 2030, to derive an evolving national fleet fuel consumption (business as usual) through these years ($\varepsilon_f(t)$ in L/100 km), assuming an annual turnover of the fleet equivalent to a lifetime of 11 years. Subscript n denotes 'new' and subscript f denotes 'fleet'.

$$\varepsilon_f(t) = \varepsilon_f f(t-1) \times 0.909 + \varepsilon_n(t) \times 0.091 \qquad L/100km \qquad A2.$$

This reflects the ongoing reduction in fuel consumption that has characterised motor vehicle development in recent years, but without additional measures. Thus fuel consumption starts at 11.49 L/100km in 2004 and finishes as 7.06 L/100 km in 2030 in the business-as-usual case.

87 See BTRE 2005b. Above n 63, p. 91.

The carbon dioxide emissions (ξ(t) in GL) are given by:

$$\xi(t) = 2.3 \times \upsilon(t) \qquad MtCO_2 \qquad A3.$$

again based on the carbon content of the dominant fuels, petrol and diesel (respectively 2.3 and 2.7 kg/L).

The distance travelled per annum (δ(t)), is given by:

$$\delta(t) = \upsilon(t) \times \varepsilon_f(t) \qquad km \times 10^{11} \qquad A4.$$

The annual fleet averaged CO_2 emissions ($\varepsilon_c(t)$) is given by:

$$\varepsilon_c(t) = \xi(t)/\delta(t) \times 10 \qquad g\ CO_2/km \qquad A5.$$

This implies, in the business–as-usual case, average fleet CO_2 emissions of 264 g CO_2/km in 2004, decreasing to 162 in 2030. These characteristics of the fleet are summarised in Table A5.1.

The first component of a response strategy we consider is community-wide behavioural changes designed to reduce demand for car travel. The second component is a top-down approach in which it is assumed that Australia adopts a series of fuel consumption and emissions standards for new vehicle manufacturers that parallels the recently agreed standards of the European Union. The third component is the inclusion of the use of biofuels, the fourth is the inclusion of some gas-to-liquid conversion as a fuel option and the fifth is the expanding use of electric cars.

In each case we examine the impacts of these component actions on the future demand for transport energy, imported fuels and on greenhouse gas emissions.

Demand Management: We propose the linear reduction of annual energy demand for cars beyond 2010 of 1% per annum, leading to a reduction of demand below the business-as-usual case by 2030 of 20%. The mechanisms for this are examined in the main text (Section 4.1).

This is translated directly as a proportional decrease in energy use, resulting from reduced distance travelled through improved trip planning, use of public transport, etc. and thus CO_2 emitted from 2011 onwards; that is, to be 20% below business-as-usual projections by 2030.

Fuel consumption targets and technology improvement: We now consider the impact of implementing fuel consumption standards similar to those of the European Union. To estimate the annual mean fleet impact in terms of CO_2 emissions per km travelled through this period we start with the current consumption $\varepsilon_f(t)$, assuming that this remains unchanged through to 2013. Thereafter, we assume that this is modified in line with the penetration of new cars into the fleet that meet fuel consumption standards regulated for manufacturers selling cars into the Australian market, $\varepsilon_n(t)$.

Given the significantly higher fuel consumption of current motor vehicles within Australia, we have suggested the introduction of those standards be phased in slightly later but then more quickly so that 65% cars sold into the Australian market (Australian manufactured and imported cars) meet the European standard of 130 g CO_2/km in 2014 and 100% by 2015. From 2018 we propose that 75% meet the 95 g CO_2/km target; 80% in 2019 and from 2020 onwards, 100% all new cars.

Again using Equation A2, the introduction of the new targets are allowed to influence the evolving fleet average fuel consumption over time. Table A5.1 shows that this leads to an improvement of fleet-averaged carbon dioxide emissions starting at 214 g CO_2/km in 2013 and reaching 124 g CO_2/km in 2030, an improvement from 162 g CO_2/km in the business-as-usual future. It has the additional benefit of reducing fuel costs as reduced CO_2 is achieved through lower fuel consumption.

New estimates of total CO_2 emissions are then derived from the previously determined distance travelled and the revised fleet carbon emissions:

$$\xi(t) = \delta(t) \times \varepsilon_c(t) \qquad [g\ CO_2] \qquad A6.$$

The energy demand is recalculated using Equation A1 and is lower in later years than those projected by BTRE[88] given the improved fuel efficiencies. Thus, we estimate the volumes of fuel required constrained by the emissions scenario.

88 See BTRE 2005b. Above n 63.

The results of these calculations through the period to 2030 are provided in Table A5.2.

Biofuels: From our discussion of biofuels, we are of the view that, subject to the more holistic examination of these as an option, they may play a significant, if relatively small role, in Australia's future motor vehicle fuel provision. Thus for the preparation of our nominal scenario, we take this component to grow from zero, growing linearly in time to the equivalent of 10% of 2010 business-as-usual liquid fuel use by 2030. We assume that to a close approximation, the CO_2 emissions and energy content of biofuels is similar to that of petrol and diesel, and thus in Table A5.3 and A5.4 we calculate impact on both CO_2 and energy demand (in energy and volume) on this basis. This assumption is a crude approximation given the significantly different energy contents of alternative biofuels. For example, the energy content per litre of ethanol is significantly lower than that of petrol. We have assumed that with this modest level of biofuels in the future mix, this is a component that delivers a saving of CO_2 emissions equivalent to the carbon content of the fuels. This is debatable, as is discussed in the main text.

Gas-to-liquid conversion: As with biofuels, the conversion of gas to liquid fuels for transport may deliver partial independence from imported liquid fuels and a level of national fuel security, but may not simultaneously deliver improved greenhouse gas emissions reduction. For our notional scenario we have assumed that the process also achieves an emissions reduction consistent with the carbon content of the liquid fuel import otherwise avoided. This is a best-case scenario. The reader can examine the outcomes with or without this assumption in the main text.

For the notional scenario we take the introduction of gas-to-liquid fuels to commence from 2016 onwards, accounting for an energy component equivalent to 10% of the 2015 total energy usage in the business-as-usual scenario.

Electric cars: We have included electric cars as a new technology that is likely to become adopted through future years as an alternative to internal combustion driven vehicles.[89] We have assumed no significant impact of this technology until the year 2015. In that year we assume that 4% of all new vehicles purchased will be electric drive. By 2020 this fraction is assumed to grow to 24% and by 2030 to 64%, leading to a total fleet average of 7 and 33% for electric vehicles by these years respectively. The impact of this on energy sourced from oil-derived fuels, and thus the volume of fuel, is calculated by decreasing the energy and volume by this fraction.

The impact of this on CO_2 emissions is, however, influenced both by the number of cars deriving energy from electricity (which is source-dependent) and the fact that electric cars are themselves more efficient in converting energy to kilometres travelled.

We first calculate the total kilometres travelled by all the electric vehicles, $\delta_e(t)$, from:

$$\delta_e(t) = \psi_e \times \delta(t) \qquad \text{km} \times 10^{11} \qquad \text{A7.}$$

where ψ_e is the fraction of electric cars in the fleet. The energy consumed by electric vehicles travelling this distance was calculated using an energy efficiency for electric vehicles of 20 kWh/100 km (72 PJ/10^{11} kms; see Table A5.3). This value was chosen after examination of the manufacturers' efficiency for 15 different vehicles of various sizes showed an average 16 kWh/100 km. On the basis that these figures were likely to be optimistic and based on a range that included small vehicles, we used a value of 20. Only the future will tell whether this could be reduced to 16 kWh/100 km for the average electric car.

The CO_2 emissions associated with this energy demand, $\xi_e(t)$, was assumed to be zero for electricity derived from renewable energy sources (this is an approximation only) and calculated for electricity generated using the emissions factor, E_f, for electricity derived respectively from black coal of 1.07 kg CO_2/kWh (0.297 Mt CO_2/PJ) and from brown coal, 1.38 kg CO_2/kWh (0.383 Mt CO_2/PJ). Thus:

$$\xi_e(t) = 20\delta_e(t) \times E_f \qquad \text{Mt } CO_2 \qquad \text{A8.}$$

These estimates of the carbon dioxide emissions per unit of energy produced were based on Department of Climate Change's National Greenhouse Accounts Factors.[90]

89 See Jamison (2010). Above n 26.

90 See Department of Climate Change 2009. Above n 73.

Table A5.1: Calculation of the impact of demand reduction (management; green columns) as a component of the notional future fuels scenario on total energy demand, distance travelled and volume of fuel and carbon dioxide emissions. Blue columns are published data used as basis for calculations. Grey column is the notional impact of demand reduction/management. Clear columns are the implied characteristics of the motor car fleet. Note the number of significant figures in each column does not imply the level of confidence in the figures. DM stands for 'Demand Management'.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	Energy Consumption BTRE (2005; PJ)	National fleet efficiency (ATC (2008) (L/100km)	New car (L/100km) BTRE (2005)	National Fuel efficiency (L/100km)	Volume of fuel (GL)	Distance travelled 10^{11} km	CO_2 emissions (Mt CO_2)	Energy efficiency (104J/km)	CO_2 efficiency (gCO_2/km)	Demand reduction factor	Energy consumption with DM (PJ)	Volume of fuel with DM (GL)	Distance travelled with DM (10^{11} km)	CO_2 emissions with DM ($MtCO_2$)
2004	657.4		8.37	11.49	18.78	1.635	43.20	402.2	264.3	1.00	657.4	18.78	1.635	43.20
2005	661.0	11.2	8.30	11.2	18.89	1.686	43.44	392.0	257.6	1.00	661.0	18.89	1.686	43.44
2006	663.8		817	10.92	18.97	1.737	43.62	382.2	251.2	1.00	663.8	18.97	1.737	43.62
2007	675.3		8.04	10.66	19.29	1.810	44.38	373.1	245.2	1.00	675.3	19.29	1.810	44.38
2008	688.8		7.92	10.41	19.68	1.890	45.26	364.4	239.4	1.00	688.8	19.68	1.890	45.26
2009	704.7		7.78	10.17	20.13	1.980	46.31	356.0	233.9	1.00	704.7	20.13	1.980	46.31
2010	714.5		7.60	9.94	20.41	2.054	46.95	347.9	228.6	1.00	714.5	20.41	2.054	46.95
2011	720.5		7.50	9.72	20.59	2.118	47.35	340.2	223.6	0.99	713.3	20.38	2.097	46.87
2012	725.4		7.41	9.51	20.73	2.179	47.67	332.9	218.7	0.98	710.9	20.31	2.136	46.72
2013	729.2		7.33	9.31	20.83	2.238	47.92	325.9	214.1	0.97	707.3	20.21	2.171	46.48
2014	732.6		7.25	9.12	20.93	2.295	48.14	319.2	209.8	0.96	703.3	20.09	2.203	46.22
2015	735.6		7.16	8.94	21.02	2.351	48.34	312.9	205.6	0.95	698.8	19.97	2.233	45.92
2016	737.2		7.08	8.77	21.06	2.402	48.45	307.0	201.7	0.94	693.0	19.80	2.258	45.54
2017	738.5		6.99	8.61	21.10	2.451	48.53	301.4	198.0	0.93	686.8	19.62	2.279	45.13
2018	739.2		6.91	8.46	21.12	2.496	48.58	296.1	194.6	0.92	680.1	19.43	2.297	44.69
2019	739.9		6.83	8.31	21.14	2.544	48.62	290.9	191.1	0.91	673.3	19.24	2.315	44.25
2020	740.9		6.75	8.17	21.17	2.591	48.69	286.0	187.9	0.90	666.8	19.05	2.332	43.82
2021	742.0		6.69	8.03	21.20	2.640	48.76	281.1	184.7	0.89	660.4	18.87	2.350	43.40
2022	743.1		6.63	7.91	21.23	2.684	48.83	276.9	181.9	0.88	653.9	18.68	2.362	42.97
2023	744.2		6.56	7.78	21.26	2.733	48.91	272.3	178.9	0.87	647.5	18.50	2.378	42.55
2024	745.3		6.50	7.67	21.29	2.776	48.98	268.5	176.4	0.86	641.0	18.31	2.388	42.12
2025	746.4		6.44	7.55	21.33	2.825	49.05	264.3	173.7	0.85	634.4	18.13	2.401	41.69
2026	747.5		6.38	7.45	21.36	2.867	49.12	260.8	171.4	0.84	627.9	17.94	2.408	41.26
2027	748.6		6.32	7.34	21.39	2.914	49.19	256.9	168.8	0.83	621.3	17.75	2.419	40.83
2028	749.7		6.25	7.24	21.42	2.959	49.27	253.4	166.5	0.82	614.8	17.56	2.426	40.40
2029	750.8		6.19	7.15	21.45	3.000	49.34	250.3	164.5	0.81	608.1	17.38	2.430	39.96
2030	751.9		6.13	7.06	21.48	3.043	49.41	247.1	162.4	0.80	601.5	17.19	2.434	39.53

Table A5.2: Calculation of the net impact of demand reduction (management; net impact in green) on energy demand, and volume of fuel and carbon dioxide emissions. Also included is the impact of new car efficiency targets (light grey) on fleet efficiency (darker grey) as a component of the notional future fuels scenario on total energy demand, and volume of fuel and carbon dioxide emissions (light orange) and net contribution (darker orange). Similarly, introduction of biofuels at a rate defined by the notional scenario in the grey column produces an impact on energy demand, and volume of fuel and carbon dioxide emissions are shown respectively in the brown columns. Note the number of significant figures in each column does not imply the level of confidence in the figures. DM stands for 'Demand Management'; 'targets' refers to the fuel consumption targets.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Year	Energy reduction due to DM (PJ)	CO_2 emissions reduction due to DM ($MtCO_2$)	Volume reduction due to DM (GL)	New efficiency targets (gCO_2/km)	CO_2 efficiency with targets (gCO_2/km)	CO_2 emissions DM + Targets ($MtCO_2$)	Volume of fuel DM + targets (GL)	Energy consumption DM + targets (PJ)	Energy reduction due to reaching target (PJ)	CO_2 reduction due to reaching target ($MtCO_2$)	Volume reduction due to targets (GL)	Biofuel factor	Energy reduction due to Biofuels (PJ)	CO_2 emissions reduction due to Biofuels ($MtCO_2$)	Volume reduction due to Biofuels (GL)
2004	0.0	0.00	0.00	264.4	264.4	43.22	18.79	657.7	-0.3	-0.02	-0.01	0.000	0.0	0.00	0.00
2005	0.0	0.00	0.00	257.6	257.6	43.44	18.89	661.0	0.0	0.00	0.00	0.000	0.0	0.00	0.00
2006	0.0	0.00	0.00	251.2	251.2	43.63	18.97	663.9	-0.1	-0.01	0.00	0.000	0.0	0.00	0.00
2007	0.0	0.00	0.00	245.1	245.1	44.36	19.29	675.1	0.2	0.01	0.01	0.000	0.0	0.00	0.00
2008	0.0	0.00	0.00	239.5	239.5	45.28	19.69	689.0	-0.2	-0.01	-0.01	0.000	0.0	0.00	0.00
2009	0.0	0.00	0.00	234.0	234.0	46.33	20.14	705.0	-0.3	-0.02	-0.01	0.000	0.0	0.00	0.00
2010	0.0	0.00	0.00	228.6	228.6	46.95	20.41	714.4	0.1	0.00	0.00	0.000	0.0	0.00	0.00
2011	7.2	0.47	0.21	223.6	223.6	46.88	20.38	713.4	-0.1	-0.01	0.00	0.005	3.6	0.23	0.10
2012	14.5	0.95	0.41	218.7	218.7	46.71	20.31	710.8	0.1	0.01	0.00	0.010	7.1	0.47	0.20
2013	21.9	1.44	0.63	214.2	214.2	46.50	20.22	707.6	-0.2	-0.02	-0.01	0.015	10.7	0.70	0.31
2014	29.3	1.93	0.84	159.5	209.2	46.09	20.04	701.4	1.9	0.12	0.05	0.020	14.3	0.94	0.41
2015	36.8	2.42	1.05	151.1	192.9	43.08	18.73	655.6	43.2	2.84	1.24	0.025	17.9	1.17	0.51
2016	44.2	2.91	1.26	146.8	178.1	40.21	17.48	611.9	81.1	5.33	2.32	0.030	21.4	1.41	0.61
2017	51.7	3.40	1.48	130.0	164.6	37.51	16.31	570.9	115.9	7.62	3.31	0.035	25.0	1.64	0.71
2018	59.1	3.89	1.69	103.8	159.1	36.54	15.89	556.1	124.0	8.15	3.54	0.040	28.6	1.88	0.82
2019	66.6	4.38	1.90	102.0	153.9	35.63	15.49	542.2	131.2	8.62	3.75	0.045	32.2	2.11	0.92
2020	74.1	4.87	2.12	95.0	148.5	34.63	15.06	527.0	139.8	9.19	4.00	0.050	35.7	2.35	1.02
2021	81.6	5.36	2.33	95.0	143.6	33.74	14.67	513.5	146.9	9.65	4.20	0.055	39.3	2.58	1.12
2022	89.2	5.86	2.55	95.0	139.2	32.88	14.30	500.3	153.6	10.09	4.39	0.060	42.9	2.82	1.22
2023	96.7	6.36	2.76	95.0	135.2	32.15	13.98	489.2	158.3	10.40	4.52	0.065	46.4	3.05	1.33
2024	104.3	6.86	2.98	95.0	131.5	31.40	13.65	477.8	163.2	10.72	4.66	0.070	50.0	3.29	1.43
2025	112.0	7.36	3.20	95.0	128.2	30.78	13.38	468.4	166.1	10.91	4.74	0.075	53.6	3.52	1.53
2026	119.6	7.86	3.42	95.0	125.2	30.15	13.11	458.8	169.1	11.11	4.83	0.080	57.2	3.76	1.63
2027	127.3	8.36	3.64	95.0	122.4	29.60	12.87	450.5	170.8	11.23	4.88	0.085	60.7	3.99	1.74
2028	134.9	8.87	3.86	95.0	120.0	29.11	12.66	443.0	171.7	11.29	4.91	0.090	64.3	4.23	1.84
2029	142.7	9.37	4.08	95.0	117.7	28.60	12.44	435.3	172.9	11.36	4.94	0.095	67.9	4.46	1.94
2030	150.4	9.88	4.30	95.0	115.6	28.14	12.24	428.2	173.3	11.39	4.95	0.100	71.5	4.70	2.04

Table A5.3: Calculation of the impact of demand reduction (management), new car fuel consumption targets, and the use of biofuels as components of the notional future fuels scenario on total energy demand, and volume of fuel and carbon dioxide emissions (brown column). The notional rates of introduction of gas-to-liquid conversions and electric cars (both in grey columns) are calculated for the former to impact on the total energy demand, and volume of fuel and carbon dioxide emissions (dark pink column) with a net contribution shown in the light pink column. The penetration of electric vehicles into the Australian fleet is given in the blue columns. Note the number of significant figures in each column does not imply the level of confidence in the figures. DM stands for 'Demand Management'; 'target' refers to the fuel consumption targets; 'BF' stands for 'biofuel'.

	31	32	33	34	35	36	37	38	39	40	41	42
Year	CO_2 emissions with DM + targets + BF ($MtCO_2$)	Volume fuel with DM + targets + BF (GL)	Energy consumption with DM + targets + BF (PJ)	Gas-to-liquid factor	Energy reduction due to gas-to-liquid (PJ)	CO_2 emissions reduction due to gas to liquid ($MtCO_2$)t	Volume reduction due to gas-to-liquid (GL)	CO_2 emissions withDM + T + BF + gas-to-liquid ($MtCO_2$)	Volume fuel consumption with DM + targets + BF + gas-to-liquid (GL)	Energy consumption with DM+ targets + BF + gas-to-liquids(PJ)	New electric car sales factor	Electric car fleet penetration (%)
2004	43.22	18.79	657.7	0.000	0.0	0.00	0.00	43.22	18.79	657.7	0.0	0
2005	43.44	18.89	661.0	0.000	0.0	0.00	0.00	43.44	18.89	661.0	0.0	0
2006	43.63	18.97	663.9	0.000	0.0	0.00	0.00	43.63	18.97	663.9	0.0	0
2007	44.36	19.29	675.1	0.000	0.0	0.00	0.00	44.36	19.29	675.1	0.0	0
2008	45.28	19.69	689.0	0.000	0.0	0.00	0.00	45.28	19.69	689.0	0.0	0
2009	46.33	20.14	705.0	0.000	0.0	0.00	0.00	46.33	20.14	705.0	0.0	0
2010	46.95	20.41	714.4	0.000	0.0	0.00	0.00	46.95	20.41	714.4	0.0	0
2011	46.65	20.28	709.9	0.000	0.0	0.00	0.00	46.65	20.28	709.9	0.0	0
2012	46.24	20.10	703.6	0.000	0.0	0.00	0.00	46.24	20.10	703.6	0.0	0
2013	45.79	19.91	696.8	0.000	0.0	0.00	0.00	45.79	19.91	696.8	0.0	0
2014	45.15	19.63	687.1	0.000	0.0	0.00	0.00	45.15	19.63	687.1	0.0	0
2015	41.91	18.22	637.7	0.000	0.0	0.00	0.00	41.91	18.22	637.7	0.04	0.4
2016	38.80	16.87	590.4	0.007	4.9	0.32	0.14	38.48	16.73	585.5	0.08	1.1
2017	35.87	15.60	545.9	0.013	9.8	0.64	0.28	35.23	15.32	536.1	0.12	2.1
2018	34.66	15.07	527.5	0.020	14.7	0.97	0.42	33.70	14.65	512.8	0.16	3.3
2019	33.51	14.57	510.0	0.027	19.6	1.29	0.56	32.22	14.01	490.4	0.20	4.8
2020	32.28	14.04	491.2	0.033	24.5	1.61	0.70	30.67	13.34	466.7	0.24	6.6
2021	31.16	13.55	474.2	0.040	29.4	1.93	0.84	29.23	12.71	444.7	0.28	8.5
2022	30.06	13.07	457.5	0.047	34.4	2.26	0.98	27.80	12.09	423.1	0.32	10.7
2023	29.09	12.65	442.7	0.053	39.2	2.58	1.12	26.52	11.53	403.5	0.36	13.0
2024	28.11	12.22	427.8	0.060	44.1	2.90	1.26	25.21	10.96	383.6	0.40	15.4
2025	27.26	11.85	414.8	0.067	49.1	3.22	1.40	24.03	10.45	365.7	0.44	18.0
2026	26.39	11.48	401.6	0.073	53.9	3.54	1.54	22.85	9.93	347.7	0.48	20.8
2027	25.61	11.14	389.8	0.080	58.8	3.87	1.68	21.75	9.45	330.9	0.52	23.6
2028	24.89	10.82	378.7	0.087	63.8	4.19	1.82	20.70	9.00	314.9	0.56	26.6
2029	24.14	10.50	367.4	0.093	68.6	4.51	1.96	19.63	8.54	298.8	0.60	29.6
2030	23.45	10.19	356.8	0.100	73.6	4.83	2.10	18.61	8.09	283.2	0.64	32.7

Table A5.4: Calculation of the impact of electric cars on fossil-liquid fuel demand reduction and carbon dioxide emissions related to alternative sources of the electrical energy for these vehicles. 'DM' stands for 'Demand Management'; 'targets' refers to the fuel consumption targets, 'BF' stands for 'biofuel' and 'G2L' stands for 'gas to liquid'. Note the number of significant figures in each column does not imply the level of confidence in the figures.

	43	44	45	46	47	48	49	50	51	52	53	54	55
Year	Electric car liquid fuel energy avoided (PJ)	Distance travelled by electric cars (10^{11} km)	Electric car energy use. (PJ)	Electric car liquid fuel CO_2 avoided ($MtCO_2$)	Electric car liquid fuel volume avoided (GL)	CO_2 emissions with DM + targets + BF+G2L+E ($MtCO_2$)	Volume fuel consumption with DM + targets + BF + G2L+ E (GL)	Energy consumption with DM + targets + BF + G2L + E (PJ)	CO_2 emissions from brown coal electricity generation ($MtCO_2$)	Intervention but brown coal electricity generation ($MtCO_2$)	CO_2 emissions from black coal electricity generation ($MtCO_2$)	Intervention but black coal electricity ($MtCO_2$)	CO_2 emissions DM + targets +BF + G2L ($MtCO_2$)
2004	0.0	0.0	0.0	0.00	0.00	43.22	18.79	657.7	0.00	43.22	0.00	43.22	43.22
2005	0.0	0.0	0.0	0.00	0.00	43.44	18.89	661.0	0.00	43.44	0.00	43.44	43.44
2006	0.0	0.0	0.0	0.00	0.00	43.63	18.97	663.9	0.00	43.63	0.00	43.63	43.63
2007	0.0	0.0	0.0	0.00	0.00	44.36	19.29	675.1	0.00	44.36	0.00	44.36	44.36
2008	0.0	0.0	0.0	0.00	0.00	45.28	19.69	689.0	0.00	45.28	0.00	45.28	45.28
2009	0.0	0.0	0.0	0.00	0.00	46.33	20.14	705.0	0.00	46.33	0.00	46.33	46.33
2010	0.0	0.0	0.0	0.00	0.00	46.95	20.41	714.4	0.00	46.95	0.00	46.95	46.95
2011	0.0	0.0	0.0	0.00	0.00	46.65	20.28	709.9	0.00	46.65	0.00	46.65	46.65
2012	0.0	0.0	0.0	0.00	0.00	46.24	20.10	703.7	0.00	46.24	0.00	46.24	46.24
2013	0.0	0.0	0.0	0.00	0.00	45.79	19.91	696.8	0.00	45.79	0.00	45.79	45.79
2014	0.0	0.0	0.0	0.00	0.00	45.15	19.63	687.1	0.00	45.15	0.00	45.15	45.15
2015	2.3	0.0	0.6	0.15	0.07	41.76	18.15	635.4	0.24	42.14	0.18	42.09	41.91
2016	6.2	0.0	1.8	0.41	0.18	38.07	16.55	579.3	0.70	39.18	0.54	39.02	38.48
2017	11.0	0.1	3.6	0.72	0.31	34.50	15.00	525.1	1.39	36.62	1.08	36.30	35.23
2018	17.0	0.1	6.0	1.12	0.49	32.58	14.16	495.7	2.29	35.98	1.77	35.47	33.70
2019	23.7	0.1	8.9	1.56	0.68	30.66	13.33	466.6	3.40	35.62	2.63	34.86	32.22
2020	30.7	0.2	12.3	2.02	0.88	28.65	12.46	436.0	4.70	35.38	3.65	34.32	30.67
2021	38.0	0.2	16.2	2.49	1.08	26.73	11.62	406.8	6.21	35.44	4.82	34.04	29.23
2022	45.1	0.3	20.6	2.97	1.29	24.84	10.80	378.0	7.90	35.70	6.12	33.93	27.80
2023	52.4	0.4	25.5	3.44	1.50	23.08	10.03	351.2	9.78	36.30	7.58	34.10	26.52
2024	59.2	0.4	30.9	3.89	1.69	21.32	9.27	324.4	11.82	37.03	9.16	34.37	25.21
2025	66.0	0.5	36.7	4.33	1.88	19.70	8.57	299.8	14.05	38.08	10.98	34.93	24.03
2026	72.2	0.6	42.8	4.74	2.06	18.11	7.87	275.5	16.41	39.26	12.73	35.58	22.85
2027	78.1	0.7	49.5	5.13	2.23	16.61	7.22	252.8	18.97	40.71	14.71	36.45	21.75
2028	83.6	0.8	56.6	5.49	2.39	15.20	6.61	231.3	21.66	42.36	16.80	37.49	20.70
2029	88.4	0.9	63.9	5.81	2.53	13.82	6.01	210.3	24.48	44.12	18.99	38.62	19.63
2030	92.7	1.0	71.7	6.09	2.65	12.52	5.44	190.5	27.46	46.07	21.29	39.91	18.61

Table A5.5: Calculation of the notional future fuels scenario on the cost of imported oil. The cost is assessed in today's dollars for business-as-usual (BAU) and with the interventions assuming no inflation of oil price and with inflation as described by CSIRO (2008). Note the number of significant figures in each column does not imply the level of confidence in the figures.

	56	57	58	59	60	61	62	63	64	65	66	67
Year	National petrol + condensate product relative to 2004 Jamison 2008	Fuel production nationally (PJ)	Imported fuel (PJ) with BAU	Imported fuel (GL) with BAU	Imported fuel costs (today's $) with BAU	Imported fuel (PJ)	Imported fuel (GL)	Imported fuel (today's $) with intervention (B$)	Imported saving (today's $) with intervention (B$)	Oil price inflation factor CSIRO (2008)	Import fuel costs with BAU and inflation (B$)	Import costs with intervention + inflation (B$)
2004	1.000	261.1	396.3	11.32	9.2	396.6	11.33	9.2	0.0	40	3.9	3.9
2005	1.090	284.7	376.3	10.75	8.7	376.3	10.75	8.7	0.0	50	4.6	4.6
2006	1.144	298.7	365.1	10.43	8.4	365.2	10.43	8.4	0.0	70	6.2	6.2
2007	1.179	307.8	367.5	10.50	8.5	367.3	10.49	8.5	0.0	75	6.7	6.7
2008	1.109	290.0	398.8	11.39	9.2	399.0	11.40	9.2	0.0	100	9.7	9.7
2009	1.070	263.7	441	12.60	10.2	441.3	12.61	10.2	0.0	95	10.2	10.2
2010	0.925	241.5	473	13.51	10.9	472.9	13.51	10.9	0.0	200	23.0	23.0
2011	0.836	218.3	502.2	14.35	11.6	491.6	14.04	11.4	0.2	212	25.9	25.4
2012	0.761	198.7	526.7	15.05	12.2	504.9	14.43	11.7	0.5	221	28.3	27.2
2013	0.672	175.5	553.7	15.82	12.8	521.3	14.90	12.1	0.7	216	29.1	27.4
2014	0.637	166.3	566.3	16.18	13.1	520.8	14.88	12.0	1.1	120	16.5	15.2
2015	0.637	166.3	569.3	16.27	13.2	469.1	13.40	10.9	2.3	177	24.5	20.2
2016	0.597	155.9	581.3	16.61	13.4	423.4	12.10	9.8	3.7	166	23.5	17.1
2017	0.582	152.0	586.5	16.76	13.6	373.1	10.66	8.6	4.9	161	23.0	14.6
2018	0.547	142.8	596.4	17.04	13.8	352.9	10.08	8.2	5.6	148	21.5	12.7
2019	0.527	137.6	602.3	17.21	13.9	329.0	9.40	7.6	6.3	173	25.4	13.9
2020	0.507	132.4	608.5	17.39	14.1	303.6	8.67	7.0	7.1	177	26.2	13.1
2021	0.493	128.7	613.3	17.52	14.2	278.1	7.95	6.4	7.8	149	22.2	10.1
2022	0.453	118.3	624.8	17.85	14.5	259.7	7.42	6.0	8.4	121	18.4	7.6
2023	0.443	115.7	628.5	17.96	14.5	235.5	6.73	5.4	9.1	93	14.2	5.3
2024	0.428	111.8	633.5	18.10	14.7	212.6	6.08	4.9	9.7	94	14.5	4.9
2025	0.398	103.9	642.5	18.36	14.9	195.9	5.60	4.5	10.3	95	14.9	4.5
2026	0.383	100.0	647.5	18.50	15.0	175.5	5.01	4.1	10.9	96	15.1	4.1
2027	0.363	94.8	653.8	18.68	15.1	158.0	4.51	3.7	11.5	97	15.4	3.7
2028	0.343	89.6	660.1	18.86	15.3	141.7	4.05	3.3	12.0	98	15.7	3.4
2029	0.338	88.3	662.5	18.93	15.3	122.0	3.49	2.8	12.5	99	16.0	2.9
2030	0.328	85.6	666.3	19.04	15.4	104.9	3.00	2.4	13.0	100	16.2	2.6

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The Electric Vehicles Revolution

Summary

In the time that has elapsed since our last Jamison report was issued, the situation regarding Electric Vehicles (EVs) has been transformed. Car makers are now lining up to announce new mass production models and moving on from hybrids to plug-in hybrids and now full electric (battery) vehicles. Battery producers are moving to mass production of new lithium-ion power packs as well as Nickel Metal Hydride versions utilised so far by Toyota in their hybrid vehicles. Proposals for charging infrastructure in city-wide networks are being announced, as well as new tax-based policy frameworks for encouraging the take-up of electric vehicles.

The possibilities for the transformation of electric power grids, with opportunities for smart-charging and smart peak-load management, are starting to be grasped, with fleets of EVs being seen not just as transport systems but as virtual power plants, storing power for use by smart grid operators. The possibility of using EVs as a means of increasing the penetration of renewable energy sources into the electricity grid is now a reality, and must be captured through appropriate policy settings. The multiple goals presented and opportunities thus generated are momentous, and offer a fresh start for automotive and energy systems alike.

Australia must be part of this transformation, both as a leader in promoting EVs as well as being a producer of the vehicles themselves, their key components and the infrastructure required. We see the electric vehicles revolution as the best way for reducing Australia's dependence on oil imports in the near term and the best means of stimulating a new kind of public electric energy system under appropriate public policy guidance. Provided policies are enacted to ensure EVs are powered with renewable sources of electricity, these vehicles can also be a means of reducing the transport sector's contribution towards Australia's greenhouse gas emissions (currently at 13%).[1]

1 Australia's transport sector accounts for 13.2% of total Australian greenhouse gas emissions. The rest come from energy generation (including electricity) (48.8%), agriculture (14.9%), fugitive emissions (6.3%), land use, land use change and forestry (9.4%), industrial processes (5.1%) and waste (2.4%). Department of Climate Change 2007. Australian national greenhouse accounts National Inventory by Economic sector 2007. Available at: http://www.climatechange.gov.au/climate-change/~/media/publications/greenhouse-report/NIES.ashx.

Contents

1. Introduction

Electric Vehicles, once a pipe dream, are now a reality. Together with other innovations designed to reduce our reliance on oil and cut noxious exhaust emissions, they are at the forefront of a revolution to introduce a low-carbon economy. A new era beckons, and it's one that Australia must take its place in.

smart for two electric drive 2009. © 2010 Daimler AG.

When Nissan introduced its new all-electric, mass production car, the Leaf, in August 2009, it was doing more than unveiling a new car. It was heralding a new era in energy, transport and the environment. Nissan's Leaf electric vehicles (EVs) are zero-emission vehicles in the sense that they emit no greenhouse gases when they run off electric power generated from renewable sources. They consume no oil. They have no noxious emissions such as carbon particulates that poison the air and the people who breathe the air. They represent a new era for private transport. Indeed, they represent a transport revolution.

What makes the Leaf and other vehicles like it ground-breaking is that it is to be more convenient than conventional petrol-driven internal combustion engine cars and cheaper to drive. If batteries can be supplied by subscription (as, for example, in the business model of the company Better Place) then the cost of running the EV itself may fall to around 5 or 6 c/km, a cost which is reducing by each year as battery learning curve effects are captured. Even allowing for efficiency improvements in internal combustion engine vehicles, and not accounting for any change in the price of fuel for these vehicles, the per kilometre cost of running EVs is favourable. The current running cost of an efficient internal combustion engine vehicle is around 6c/km based on fuel consumption of 5L/100km and a fuel price of $1.20/L. Although the capital costs of EVs, including their batteries, are still much higher than the capital costs of internal combustion engines of equivalent size, this difference is likely to shrink as the market for EVs grows.

Moreover, the Leaf and other EVs will potentially have the additional positive impact of assisting in integrating renewable energy sources into the electricity grid. The reduction of greenhouse emissions would be assisted by the building of a new integrated transport-cum-renewable energy industry, based on new vehicle charging infrastructure and a new 'smart grid'. The 'smart grid' may potentially enable electric utilities to even out the loads and utilise EVs as grid management and energy storage systems – allowing extra EVs to potentially be put on the road without having to build new conventional fossil fuel power stations. To achieve this, the people driving EVs would have to ensure that their cars utilise electricity generated from renewable sources such as sun, wind and biomass.

All of this is potential; it remains to be realised. Mass production EVs could be an important fillip in driving the adoption worldwide – and in Australia – of a low-carbon economy. Equally, the potential may fail to be realised. A report by

Australia must make radical changes to shift vehicle production to newer technologies in order to remain relevant.

AutoCRC *Automotive Australia 2020*[2] recognises the growing public demand for global and Australian automotive and related industries to produce 'greener', more energy efficient vehicles. The Australian automotive industry is facing growing pressures from emerging auto manufacturers – particularly from Asia – to produce low or zero-emission vehicles. The report states that Australia must make radical changes to shift vehicle production to newer technologies in order to remain relevant and benefit from investment and industry expansion opportunities.

We wish to be realistic about these new developments. The last thing we want to see is the mass adoption of EVs without corresponding changes in the generation of electricity, so that adoption of EVs would actually lead to an increase in fossil energy consumption and an increase in greenhouse gas emissions from coal or gas-fired power stations. We wish to encourage policy changes that direct Australian motorists as a whole to increase their use of renewable energy sources via EV adoption and thus reduce greenhouse gas emissions. We envisage a tax concessions system that reduces taxes on EVs (e.g. state registration taxes), subject to vehicle owners being able to demonstrate that they have green sources for their electricity – either because they are generating it themselves from wind or solar sources, or because they have mandated their electricity provider to source their electric power from Green Power. Since the EV revolution and resultant transformation of energy and transport systems is still a few years away in Australia, there is time to discuss such policy changes and put them into effect.

The development of an EV future promises comprehensive change and opens up many opportunities for redesign of industrial systems while latecomers to the industrial scene such as China are presented with special opportunities – and are taking advantage of them. Political leaders in China are taking every opportunity to explain why their country is taking such extraordinary initiatives in the field of EVs (as we discuss below).

2 AutoCRC 2009. *Automotive Australia 2020 Vision*, available at: http://www.autocrc.com/files/File/2009/AA2020_web2.pdf.

Political leaders in the United States, the European Union and Japan are also quick to explain why they are doing everything they can to transform their fossil-fuelled transport systems into renewable energy and electrically oriented systems.

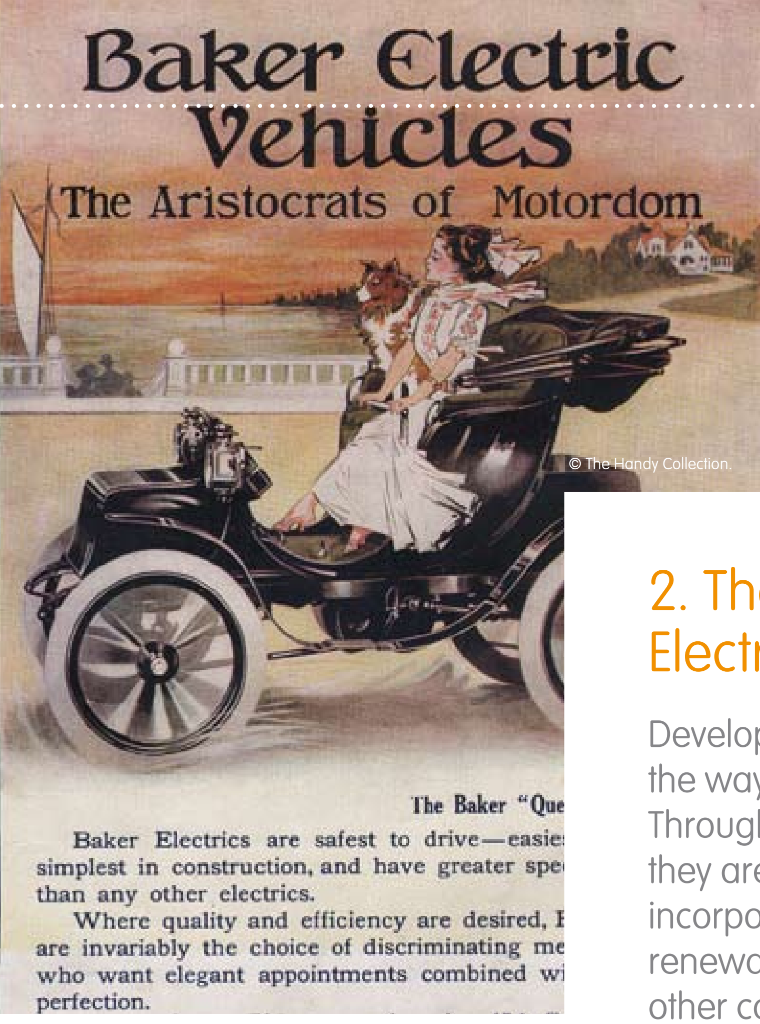
In the United Kingdom, there has been a commitment by the government to make Britain 'the European capital for electric cars' or the 'green car capital of Europe'. Prime Minister Gordon Brown pledged 90 million pounds in an announcement made at the British International Motor Show in September 2008; he said the money would be available over five years to support electric and hybrid car projects.[3]

These changes can be expected to start taking place in Australia in 2012 – after earlier roll-outs of EV charging infrastructure in Israel in 2010 and Denmark in 2011. Thus we – NRMA and public authorities in Australia – have ample advance warning and time to put preparations in place. We should be aiming for a substantial proportion of new additions to the Australian vehicle fleet to be EVs by 2020, i.e. within a decade, with the majority of the urban fleet consisting of EVs by 2030.

These are the prospects opened up by the new mass production proposals for EVs and the new proposals for provision of infrastructure needed to turn EVs into a pressing and immediate reality (such as multiple charging points in Australian cities). To date we have heard little or nothing at all from Federal Government leaders in Australia as to how to further expand EV infrastructure and what advantages are to come from it.

The world has changed – and Australia has to change with it. This report to NRMA from the Jamison Group is designed to trigger a change in thinking in Australia and a change in the behaviour of our business and political elite. It is presented together with a companion report which looks at alternative transport fuels, technology and infrastructure (Jamison *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia* 2010). Australia cannot afford to miss the opportunities presented by the EV transformation of energy and transport systems.

3 The Rt Hon Dr. James Gordon Brown MP quoted in 'European capital for electric cars,' Beyond Fossil Fuel.com, 8 September 2008, available at: http://www.beyondfossilfuel.com/electric/europe_080908.html.



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© Toyota Australia.

2. The development of Electric Vehicles

Developments in mass production of EVs are leading the way in zero-emissions mobility. But that's not all. Through partnerships with infrastructure providers, they are setting examples for a holistic approach incorporating batteries, electricity grid networks and renewable energy sources. It's an approach that other car makers and government should take heed to follow.

© Toyota Australia.

The new mass production EVs exhibited by Renault-Nissan at the Frankfurt Motor Show are the product of a lengthy evolution. The Nissan Leaf is a medium-sized hatchback that can seat five adults and has a range of 160 km, which is more than enough for most city driving. The core of the car is an electric motor powered by a pack of laminated compact lithium-ion batteries, which generate a power output of 90 kW. Unlike its internal combustion engine-powered rivals, which consume oil, the Nissan Leaf has no tailpipe, and thus emits no carbon dioxide (CO_2) or other greenhouse gases or noxious gases and particles. (Of course its manufacture entails some greenhouse gas emissions, but these should not be allowed to obscure the revolutionary shift that the car represents.)

It derives its power from the energy stored in the lithium-ion battery pack, supplemented by energy recovered by regenerative braking (meaning that the battery can be charged by the car's braking). The car can be charged at home through a 110V or 220V outlet overnight (taking eight hours for a full charge) or to 80% through a quick charge at a higher voltage plug-in facility (probably 480V at 100 amps) that Nissan will be pressing for at service stations, parking lots and other commercial centres and some domestic residential buildings. (However, rapid charging could reduce the life of the batteries.) It is these specialised charging outlets that we would want to see reserved for Green Power, i.e. electricity generated from renewable sources.

The Nissan Leaf is the first in the company's forthcoming line of EVs and is a major milestone in the realisation of the Renault-Nissan Alliance's vision for zero-emission mobility. The first of Nissan's EVs will be manufactured at Oppama, Japan, with additional capacity planned for Smyrna, Tennessee, in the United States. Meanwhile, lithium-ion batteries are being produced in Zama, Japan, with additional capacity planned for the United States, the United Kingdom and Portugal, with other sites for investment under study around the world.

At the Frankfurt Motor Show, the Renault-Nissan Alliance exhibited three new EV models, one of which was a production model, i.e. one ready to go into mass production. This production electric car from Renault is named the Fluence, and is based on the existing Mégane sedan (i.e. a family car).[4] The arresting feature of the Fluence is that it comes with a quick-change battery replacement feature – termed 'Quick Drop' – that is compatible with the Better Place approach to battery switching (see boxed text on page 98). Thus the battery in the Renault Fluence will be a battery pack that can be replaced at a battery swap station, standardised to work with the Better Place open source technology and the technology being jointly developed by Renault with EDF (Europe's biggest electricity utility) in France.

This is an example of complementarity between two companies, in this case the EV provider (the Renault-Nissan Alliance) producing the car and the infrastructure provider (Better Place) providing the recharging and battery switching systems, both designed to be compatible with each other. It brings out the significance of standards and their importance in driving (or curtailing) a new industry's growth. In this case the companies are committed to driving rapid growth of EVs as a new industry, and both are **setting open standards and producing to these standards to help the process along**. This example also dramatically reveals how the development of the EV involves the development of a new system (a holistic development) that spans vehicles, batteries, electricity grid and renewable energy sources – with changes in each of these streams triggering and reinforcing changes in the others.

4 In physics, fluence is the radiative flux integrated over time. The name thus conjures up an image of radiation, intensity and, in general, scientific sophistication.

A big leap forward will occur when hybrids can be connected to the mains electricity grid to top up the charge in their batteries.

Electric vehicle evolution

EVs have evolved through several stages of electrification and will continue to do so. They have taken the form of various kinds of hybrids culminating in the all-electric vehicles now being exhibited.

Hybrid electric vehicles

Hybrid electric vehicles (HEVs) combine a conventional internal combustion engine with an electric motor as a back-up. By designing the car to allow the electric motor to take over from the conventional engine at points during the drive cycle, the hybrid is able to reduce oil consumption (petrol or diesel) and reduce its greenhouse gas emissions, especially during urban 'start-stop' driving. In one configuration, the internal combustion engine continues to drive the wheels and charges the battery while the internal combustion engine is operating at its maximum efficiency during long distance driving, adding to the electrical energy generated through regenerative braking. While accelerating at low speed, the vehicle uses only the electric motor and batteries. This is the configuration of the Toyota hybrids like the Prius and Camry. The latter is a flexible design in which the vehicle can be driven by the motor alone, the engine alone, or both together.

Another version of the hybrid involves simplifying the car so that the electric motor only drives the wheels, and the conventional engine is a small device used to extend the range of the electric vehicle, cutting in as the charge in the battery starts to get low. This is the design of forthcoming hybrids such as the GM Volt; it is known as a 'serial' or 'series hybrid' design in the sense that the EM and the internal combustion engine are connected in series.

Plug-in hybrid electric vehicles

A big leap will occur when hybrids can be connected to the mains electricity grid to top up the charge in their batteries. Toyota plans to release such plug-in hybrid electric vehicles (PHEVs) in the next year; they will be known as third-generation hybrids. They will be released first in Japan, and then the United States. However, the Chinese firm Build Your Dreams (BYD) stole a march on Toyota when it introduced the world's first mass-produced PHEV at its Shenzhen plant in December 2008 – destined for sale in China and in the United States this year. Australia should have PHEVs available for purchase from Mitsubishi, Toyota and other companies such as BYD in the next couple of years. The BYD plug-in hybrid is, in essence, an electric vehicle equipped with a back-up internal combustion engine power unit that is only used once the batteries in the vehicle are depleted to allow the vehicle extra range. Once new recharging infrastructures are established the internal combustion engine may not be required.

All-electric vehicles (battery electric vehicles)

The culmination of this evolution is the all-electric vehicle, or battery EV, where the power is supplied by the grid and stored in an advanced battery, using an advanced technology such as nickel metal hydride (NiMH) or lithium-ion technology. Although electric delivery vehicles with lead-acid batteries were used in the 1960s in the United Kingdom, electric passenger vehicles were very rare at that time. The reasons that battery EVs have now become feasible and practicable, far faster than anyone would have guessed, are firstly due to advances in battery design and performance, so that more power and charge is held per unit weight. Secondly, they are due to the development of infrastructure in the form of charging devices – which in turn have triggered companies like Renault-Nissan to accelerate their introduction of mass production Battery EVs. The Nissan Leaf and the Renault Fluence are all-electric cars. The vehicles themselves are only part of a potential EV clean transport system. The complementary part is the electric grid and the charging systems that make it connectable.

Grid system changes

From being the laggard in global warming forums, the transport sector could become the leader in reducing dependence on oil and in reducing greenhouse gas emissions – if ambitious plans to establish nationwide EV systems come to fruition (see also Jamison *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia* 2010). Israel is the first country to sign on to a new strategy of eliminating oil dependence in private transport within a decade. The key to the new strategy is to focus not on the cars, or the batteries or the sources of electric power, as such. All are important as elements of a new EV system, but they make little headway without the missing ingredient, namely a nationwide infrastructure of charging stations where EVs' batteries may be charged (or replaced) easily and quickly. It is the proposal by a private firm to provide such an infrastructure in advance of the transition to EVs, and the adoption of this plan by the Israeli government that has set the country on a new path to oil independence.

The transport sector could become the leader in reducing dependence on oil and in reducing greenhouse gas emissions.

BETTER PLACE

The entrepreneur behind the new infrastructure-driven vision of electric vehicles is Shai Agassi, head of the Israel-backed firm Better Place, with headquarters in Palo Alto, California. The key insight of the Better Place model is to focus on the creation of a new grid of charging points, and to conceive the EV changes as ushering in a total system. If this is viewed as new infrastructure and with intelligence built in (so that it can communicate with its users and calculate the best times for recharging). If it is adopted nationwide, in a single commitment backed by tax incentives that make EV ownership more attractive than gasoline-powered vehicle ownership, then this represents a paradigm shift. Add an extra insight from Agassi, to separate battery ownership from car ownership, and offer consumers various kinds of leasing deals for batteries, in the same way that consumers buy minutes on a mobile phone, and you have a potentially very attractive model for rolling out EVs.

This is why Agassi has been able to partner with a leading automotive manufacturer, Renault-Nissan, and with energy companies and governments in Israel, Denmark, Australia, in parts of the United States and in the Canadian province of Ontario, in taking the steps needed to accomplish the vision. In this, Better Place acts as the integrator and

Battery switch in progress. © Better Place.

The uptake of EVs is likely to proceed fastest in countries that invest in the charging infrastructure.

the infrastructure provider. Agassi likes to use a mobile phone analogy, whereby Better Place is the AT&T (system provider) rather than the Nokia (handset provider) of EVs.

The first country to sign up to this model was Israel.[5] The prototype Renault EV there had its debut in Tel Aviv in May 2008, and plans are well advanced to roll out the network of charging stations and battery switching stations in 2010. (We understand that these plans involve renewable energy sources being tapped for the power to be supplied.) This was followed by Denmark, involving the Danish government as well as the main electrical energy producer, DONG Energy. Then came Australia, where the parties are the electric energy producer AGL and the finance house Macquarie Bank, with support from the State Government of Victoria. In the United States the mayors of several Bay Area cities in California (including San Francisco) signed on. At the beginning of December 2008, Hawaii became the first state in the United States to sign up for statewide coverage.[6]

A similar model to the Better Place/Renault-Nissan model is that being developed by the electricity operator EDF together with Toyota, in France. These two companies are combining to build recharging networks in France and the United Kingdom, but not yet on the scale of the Better Place model.

Charge spot. © Better Place.

EDF also has a joint venture with Elektromotive Ltd (based in Brighton, United Kingdom) to install new charging points in London and elsewhere in the United Kingdom.[7] Elektrobay proposes to make the charging grid 'intelligent' through the use of its Power Line Communication (PLC) technology, under which car driver and grid can communicate, e.g. finding out pricing and account details. In September 2009, a similar proposal for building mass infrastructure in five American states and municipalities (Oregon, San Diego, Tennessee, Seattle and the Phoenix/Tucson region) was announced by eTec (Electric Transportation Engineering Corporation) as part of a US$100 million award under the Department of Energy's EV stimulus package. Approximately 2,500 charging stations will be created in each of the five regions.

Anticipated rate of uptake of electric vehicles

A new study published by the Centre for Entrepreneurship and Technology at the University of California, Berkeley, released in mid-2009, found that given a battery switching model and pay-per-mile contracts such as proposed by Better Place, electric cars could account, in the baseline scenario, for 64% of United States light-duty vehicle sales by 2030, by which time they would comprise 24% of the United States light-duty fleet. Two other scenarios are considered: 1) a high oil price scenario (using EIA projections) and 2) a battery swap operator-subsidised scenario, whereby EV new vehicle sales penetration reaches 85% and 86% respectively by 2030.[8]

This analysis relies on a network externality model focusing on relative prices, operating costs, and the network effects of battery switching stations. The high rate of adoption would be driven by the low purchase price and lower operating costs of electric cars with switchable batteries. The uptake of EVs is likely to proceed fastest in countries that invest in the charging infrastructure, and in latecomers that look to EVs to leapfrog their automotive industries – such as China.

5 See Steven Erlanger 'Israel is set to promote the use of electric cars' *New York Times*, 21 January 2008, at: http://www.nytimes.com/2008/01/21/world/middleeast/21israel.html; and Barbara Kiviat 'Israel looks to electric cars' Time, 20 January 2008, at: http://www.time.com/time/world/article/0,8599,1705518,00.htm.

6 See John Markoff 'Hawaii endorses plans for electric cars' *New York Times*, 2 December 2008, at: http://www.nytimes.com/2008/12/03/technology/start-ups/03hawaii.html.

7 See Sami Grover 'UK utility to install 250 Electric Vehicle charging points', 7 October 2007 at: http://www.treehugger.com/files/2007/10/uk_utility_to_install_ev_charging_points.php.

8 Becker, T., Ikhlaq, S. and Tenderich, B. 2009. *Electric Cars in the United States: A New Model with Forecasts to 2030* Center for Entrepreneurship & Technology (CET) Technical Brief. Thomas Becker is a Ph.D. candidate in economics with a specialization in international finance and environmental economics. Available at: cet.berkeley.edu/dl/CET_Technical%20Brief_EconomicModel2030_f.pdf.

3. Factors driving the uptake of Electric Vehicles

For Australia's transport future to be based on the EV, several concurrent and mutually supportive developments must take place. Improvements in battery technology remain key, but they must be matched by modernisation of the grid. So too must governments legislate to ensure only renewable electricity is utilised to charge the batteries of EVs.

What is needed is government policy to ensure that only renewable electricity is used to charge the batteries of EVs.

A number of issues are involved in the move towards EV technology. They include the need to have an electricity grid and charging and recharging systems, the development of batteries and the falling costs involved, the cost projections as EVs are taken up, and the role to be played by renewable energy. In the next section we will also examine why it is that a latecomer such as China might play such an important role in the transition towards EV use – and what this means for Australia. The point to emphasise is that the EV transformation draws on several parallel streams of development – vehicles themselves, advanced batteries, grid modernisation, renewable energies uptake – and brings them together into a single developmental change.

There are three basic elements to a development strategy for the EV rechargeable grid, or what Shai Agassi refers to as the Electric Recharge Grid Operator model, which has the convenient acronym ERGO (which summons up connotations of 'erg' the SI unit for energy, coming from the Greek word 'ergon' for work). There is 1) an infrastructure of an intelligent rechargeable grid connected via the Internet; 2) partnerships with vehicle and battery manufacturers as well as with suppliers of network hardware; and 3) a means of reducing costs for consumers in taking up the EV option, e.g. by offering consumers batteries (and even cars) on a leasing arrangement, whereby fees vary with mileage driven.

What is still needed is government policy to ensure that only renewable electricity is used to charge the batteries of EVs. Good intentions are not enough.

In the countries and regions where the model is being introduced, it is anticipated that these will be backed by strong tax incentives offered by the country's government to accelerate uptake of EVs. Whether this is appropriate in Australia remains to be assessed. These elements interact to produce a powerful approach that Deutsche Bank predicts will eventually put the gasoline-powered internal combustion engine out of business.[9]

a) Electric vehicles and the electricity grid

Denmark provides an excellent case study as to why EVs are likely to transform the world's electric power grids and make renewable sources, such as wind, more acceptable and manageable. Denmark is a world leader in clean electricity generation and energy efficiency in terms of getting more GDP per unit of energy than other members of the European Union. Bioenergy accounts for about 10% and wind accounts for 20% of annual electricity generation – but there is as yet little capacity to store wind energy once it is generated. If Denmark were to increase the proportion of wind power to 50% as planned, problems would increase disproportionately due to this inability to store sufficient wind power.[10] In 1985, nuclear power was definitively abandoned as a potential energy source in Denmark.

9 See Deutsche Bank 2008. *Electric cars: Plugged in. Batteries must be included.* FITT Global Markets Research (Fundamental, Industry, Thematic, Thought Leading), 9 June 2008. New York: Deutsche Bank Securities Inc.

10 Lund, H. 2005. 'Large-scale integration of wind power into different energy systems', *Energy* Vol 30 (13): 2402-2412.

Electric vehicles have the potential to be a major source of 'trapped' energy for utility operators.

Following on from the long-term Danish energy plan, the Danish power grid has subsequently developed through establishing and/or modernising coal-fuelled power plants, while trying to utilise coal energy in the most efficient way possible. The result of these investments is an electricity system that is dominated by large-scale combined heat and power plants to the tune of 50% of power supply.[11] This system provides efficient production of energy, but at the cost of system flexibility. In particular the management of peak periods is difficult. Hence, the search for storage opportunities has been intensifying. Possible options include heat pumps and heat storage, compressed air, hydrogen storage, battery storage and the pumping of water – all solutions that individually or in some form of combination provide benefits but also have negative cost and space limitations.

At present hydro-electric dams in Norway provide some storage for the Danish electricity supply system. Investment in heat storage and heat pump facilities is another possible solution from a balancing point of view.[12] EVs could also provide a solution – as 'mobile storage devices' through recharging infrastructures and as stationary storage devices at individual wind turbines or clusters of wind turbines. This could make wind and other intermittent energy sources more reliable sources of electric power while at the same time provide a range of environmental benefits.[13]

This approach is buttressed by theoretical studies in the United States. A study by Kintner-Meyer, Schneider and Pratt (2007)[14] indicates just how much 'reserve energy' is held by the existing United States electricity grid due to its need to cover periods of high demand, and how this reserve energy could be used to power a large fleet of electric vehicles if such vehicles could provide intelligent possibilities of smoothing out peaks and valleys in demand. Once wind energy resources are fully utilised in the United States, similar utilisation problems as those found in the Danish system will be encountered.

Another study by Short and Denholm (2006)[15] of the National Renewable Energy Laboratory in the United States, reveals that plug-in electric vehicles acting as a storage resource on the grid would thus help the penetration of intermittent renewable energy generation resources such as solar and wind. The energy storage offered by the plug-in vehicles would help to smooth the peaks and valleys of renewable energy generation. This is particularly beneficial in the case of wind energy, which in many locations such as Denmark can produce the greatest amount of energy at night, during low-demand hours. Thus, electric vehicles have the potential to be a major source of 'trapped' energy for utility operators, if and when they are treated as mobile storage devices. On the other

11 Lund, H. and Münster, E, 2006. 'Integrated energy systems and local energy markets' *Energy Policy* Vol 34(10): 1152-1160.

12 See Lund 2005 above n 10.

13 Andersen P., Mathews, J. and Rask, M. 2009. 'Integrating private transport into renewable energy policy: The strategy of creating intelligent recharging grids for electric vehicles', *Energy Policy* 37 (7): 2481-2486.

14 Kintner-Meyer, M., Schneider, K. and Pratt, R. 2007. *Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. power grids. Part 1: Technical analysis, Working paper*, Pacific North-West National Laboratory, Federal Energy Regulatory Commission.

15 Short, W. and Denholm, P. 2006. *A preliminary assessment of plug-in hybrid electric vehicles on wind energy markets, Technical report NREL/TP* 620-39729. Golden, CO: National Renewable Energy Laboratory.

recognise that the majority of EV drivers will draw more energy from the grid without feeding it back and this fact will have to be taken into consideration in planning for the transition.

With a storage capacity based on coordinated control over an extended battery pack, it becomes possible to adjust electricity supply and demand effectively, creating what can be labelled a virtual power plant. The concept of a virtual power plant has mainly been developed as a means of integrating inputs from a variety of decentralised power generating devices or systems (such as wind, combined heat and power plants, bioenergy or geothermal),[16] or by combining many combined heat and power plants systems into one.[17] The possibility of utilising EVs and integrating their storage capacity as a virtual power plant provides yet another application of this idea, now being actively investigated in Denmark. Flexible wind energy would provide an additional resource in power peak situations and over the longer term make it possible to reduce the excess capacity of coal-based power plants. DONG Energy is negotiating the creation of virtual power plants (or the sale of virtual power plant capacity) under joint ownership.[18]

The capacity to pass stored energy in a vehicle's battery back to the electricity grid is known as the vehicle-to-grid (V2G) model;[19,20] and has been popularised, for example by Google.org (the non-profit arm of Google) as its RechargeIT system.[21]

Such a facility would allow electric vehicles to provide the grid operator with power that can be used for grid optimisation and stabilisation. Again the facility would be vastly enhanced by the provision of intelligence in the grid, allowing vehicle owners to communicate with the grid and determine optimal times for downloading current (charging or recharging batteries) and also for sending current to the grid (discharging batteries), pending necessary grid modifications. (No energy is created through this process; it is simply better management of peaks and loads within the existing system.) The introduction of the ERGO approach will doubtless accelerate the shift to V2G power systems, making the integration between renewable energy sources, power grids and private transport more complete.

The roll-out of new grid-to-vehicle (G2V) and, ultimately, V2G infrastructure will involve the complete overhaul of the grid itself and of the regulatory framework governing the distribution of electric power – from planning permits in city commercial areas to allow public access charging points to be erected, to the rules under which the entire grid operates. We recognise that to stimulate the modernisation of the grid and to facilitate the supply of power from renewable energy sources, gross feed-in hand we

16 Werner, T.G. and Remberg, R. 2008. 'Technical, economical and regulatory aspects of Virtual Power Plants'. *Proceedings of IEEE Conference 'Electric Utility Deregulation and Restructuring and Power Technologies'*, DRPT 2008, Nanjing, China, 2427-2433.

17 Andersen, A. and Lund, H. 2007. 'New CHP partnerships offering balancing of fluctuating renewable electricity productions', *Journal of Cleaner Productio*n 15(3): 288-293.

18 Andersen, P.H., Mathews, J.A. and Rask, M. 2009. Above n 13.

19 Tomi, J. and Kempton, W. 2007. 'Using fleets of electric-drive vehicles for grid support', *Journal of Power Source*s 168 (2). 459-468.

20 Turton, H. and Moura, F. 2008. 'Vehicle-to-grid systems for sustainable development: An integrated energy analysis', *Technological Forecasting & Social Change*' 75: 1091-1108.

21 See Rolf Schreiber 'RechargeIT V2G overview', 30 September 2008, at: http://rechargeit.blogspot.com/2008/09/vehicle-to-grid-v2g-overview.html

New advanced batteries will be a driving force behind the uptake of EVs around the world.

tariff arrangements will be needed, providing for households and larger renewable energy power stations to be paid premium rates for all renewable electricity they supply to the grid.

If we wish EVs to be part of a 'smart grid' system (as we do), then they will have to be plugged in to a high-amp circuit, because feeding back any significant amount of power from the vehicle battery to the grid will require much higher power capability than a household circuit (max. 2.4kW).

A rough estimate of the impact of electric vehicles on electricity demand highlights the critical need to legislate for renewable electricity supply. If all cars were converted to electric vehicles the annual demand on electricity would increase by 22.5-30 TWh (Terrawatt-hours) per year – the equivalent of adding 10% to Australia's annual electricity demand.

NB: This estimate is made by the authors based on examining various prototype cars using 15-20 kWh electricity/100 km (on average, driving a distance of 15000km/year) multiplied by 10 million vehicles on the road.

b) Batteries and electric vehicles

The heart of the new EV is the battery – the on-board store of energy derived from a power source. Producing cost-effective batteries that are sufficiently light has been the great barrier to the mass production of EVs. This is now about to change and new advanced batteries will be a driving force behind the uptake of EVs around the world.[22,23]

Batteries have been improving in terms of their power delivered per unit mass – getting more power out of a battery of a given volume – as well as improving in terms of their layout (being spread across a greater area of the car) and their ease of switching. Above all, battery costs have been decreasing, capturing the benefits of the 'experience curve' as shown in Figure 1.

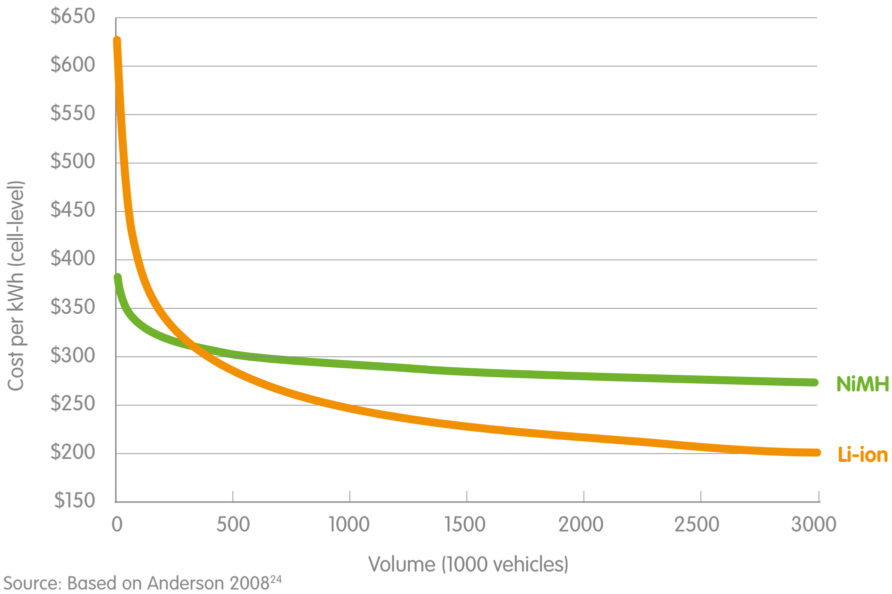
The NiMH battery is almost at the end of its technological evolution, while the patents covering it are still in force and retarding wider application of the batteries in hybrid vehicles. The size of the global lithium iron phosphate $LiFePO^4$ (LFP) market hit US$13.2 billion in 2008. The figure is expected to be US$45.9 billion in 2010 according to the conservative penetration rate of 10-20%, and the compound annual growth rate would be 28% per annum between 2008 and 2013, as shown in Figure 2.

22 Gaines, L. and Cuenca, R. 2000. *Costs of lithium-ion batteries for vehicles,* Argonne National Laboratory, Paper ANL/ESD-42. Argonne, IL.

23 TWP 2009. *The race for the electric car: A comprehensive guide to battery technologies and market development.* Principal authors Dilip Warrier, Jess Osborne, Yumi Odama. London, UK: Thomas Weisel Partners.

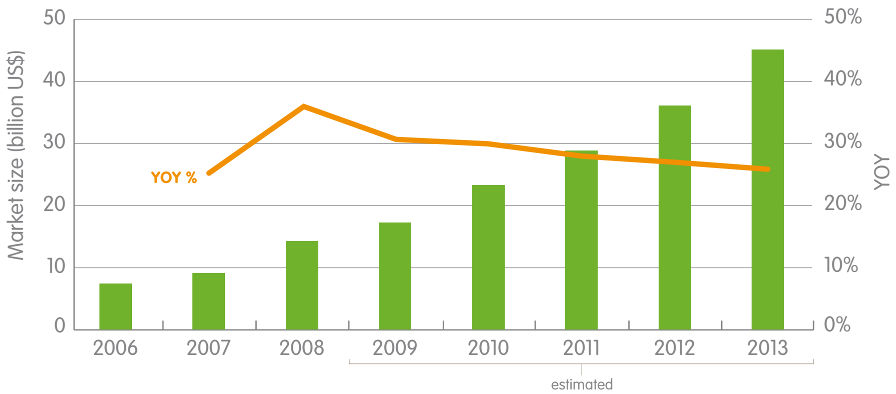
Lithium-ion batteries promise to be to the 21st century what the microprocessor was to the 20th century.

Figure 1. Experience curve for NiMH and Li-ion batteries.



Source: Based on Anderson 2008[24]

Figure 2. Size of global lithium iron phosphate market, 2006-2013.



Source: Adapted from Market Avenue, Global LFP (LiFePO4) Industry Report 2009[25]

Lithium-ion batteries promise to be to the 21st century what the microprocessor was to the 20th century. They promise to have a general impact on several new industrial developments. The lithium iron phosphate battery is a type of rechargeable battery, using LiFePO[4] as a cathode material. Developed in 1996, it was seen to have a big future because it is thermally stable, low-cost and made from abundant, non-toxic materials.

24 Anderson, D. 2008. 'Status and trends in the HEV/PHEV/EV battery industry', Presentation to CEFI conference, available at: http://www.its.berkeley.edu/sustainabilitycenter/newsandevents/CEFISrelated_anderson.pdf.

25 Adapted from Market Avenue 2009. *Report on Global LFP (LiFePO4) Industry.* See: http://www.marketavenue.cn/upload/ChinaMarketReports/REPORTS_1147.htm.

The critical issue is whether a scale up of EVs would result in unsustainable demands on the electricity grid, calling for construction of new fossil fuelled power stations.

c) Cost projections

It is unknown what the full cost implications will be and what the pricing structure will look like in relation to the introduction and use of EVs. A detailed cost analysis is yet to be undertaken with regard to associated infrastructure provision, charging of car batteries from charging stations in comparison to home charging costs and recycling of batteries. Some limited cost estimates are suggested below.

Setting aside the capital cost of the vehicle and replacement batteries, the Nissan Leaf will cost around 6 c/km to drive – based on electricity being charged at around 14 c/kilowatt hour and assuming average driving distance of 24,000 km/year – according to reported remarks from Mark Perry, Nissan's Director of product planning.[26] Some studies give figures of around 2 to 5 (US) c/km (or per mile) so we can be reasonably confident in this figure of 5 or 6 (Aust) c/km. Let us compare this with the cost of driving with a petrol-fuelled engine.

A car with a consumption of 10 km/L, at the current fuel price of about $1.20 converts to 10 c/km, a cost which is marginally higher than that suggested for the electric car, although it is expected that the latter costs will come down as the cost of batteries continues to fall. So while the costs of running the EV will likely fall in time, the costs of buying liquid fuel may rise. This is the cost differential that promises to make the difference, tipping consumer preference towards EVs.

These costings don't take into consideration the cost of EVs and internal combustion engine vehicles themselves and no effort is made here to estimate the cost of the batteries for EVs in the longer term. Currently the cost of hybrid electric vehicles is considerably more than the cost of equivalent internal combustion engine vehicles due in large part to the cost of the batteries. The learning effects already mentioned that will cause battery performance to improve should also lower the cost of battery manufacture. Economies of scale should also have the effect of reducing the cost of batteries. Parallels can be drawn between computer technology and performance and battery technology and performance.[27]

d) Greenhouse gas emissions

There are two scenarios to consider when discussing the effects on greenhouse gas emissions. If EVs are introduced without any change to the sources of electric power generation, then the reduction in emissions from car exhausts is simply transferred to the power stations that produce the electric fuel. So there is no real net gain in greenhouse gas emissions reduction. Indeed, if electricity sourced from brown coal is used, there will be a substantial increase in emissions (see Jamison *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia* 2010).

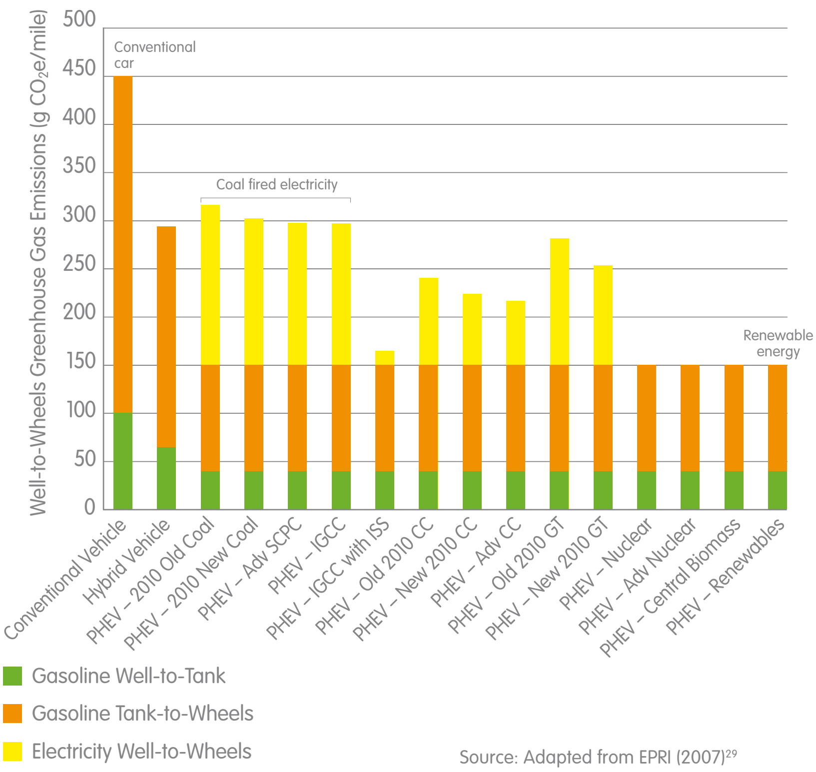
The only way to effect a reduction is to insist (mandate, regulate) that EVs be introduced with renewable energy being used for their electric fuel. Here the critical issue is whether a scale up of EVs would result in unsustainable demands on the

26 Squatriglia, C., 'Nissan turns over an electric Leaf', *Wired: Autopia*, 2 August 2009, available at: http://www.wired.com/autopia/2009/08/nissan-electric-leaf/.

27 Fetcenko M.A., Ovshinsky S.R., Reichman B., Young K., Fierro C., Koch J., Zallen A., Mays W., and Ouchi T. 2007. 'Recent advances in NiMH battery technology' *Journal of Power Sources* 165(2): 544-551.

If appropriate government and business policies are implemented to ensure that EVs are only charged by renewable energy, then EVs would truly become zero-emission vehicles.

Figure 3. Plug-in Hybrid Greenhouse Gas Emissions



Source: Adapted from EPRI (2007)[29]

electricity grid, calling for construction of new fossil fuelled power stations.[28] From the viewpoint of greenhouse gas emissions, an increase in fossil-fuelled base load is worse than peak load.

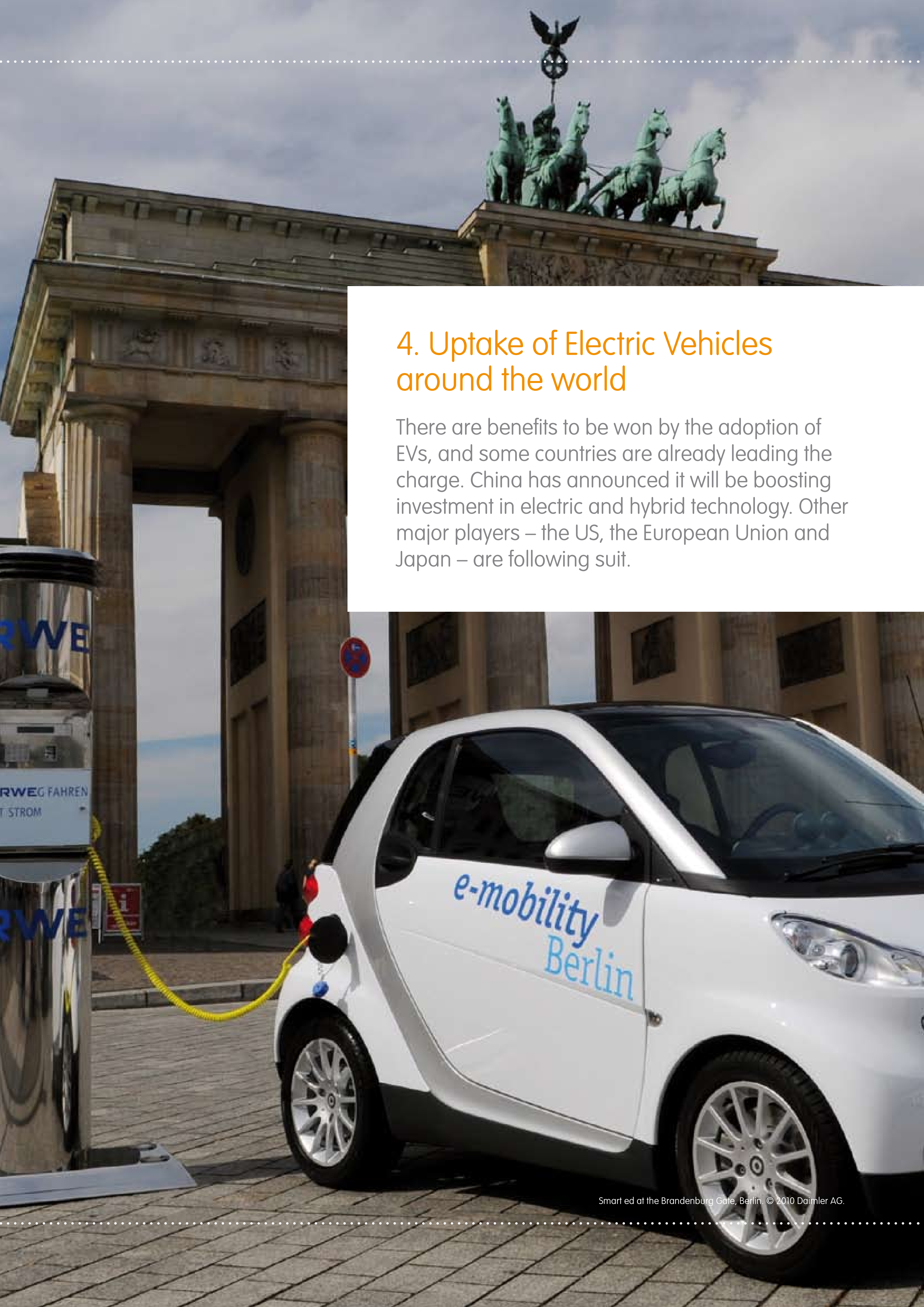
The model proposed by Better Place in Australia recommends that sufficient extra power be made available from renewable sources. The extra load from charging of EVs would be evened out over the course of each day, through the intelligence built into the grid allowing for communication between EV and charging station. If appropriate government and business policies are implemented to ensure that EVs are only charged by renewable energy, then EVs would truly become zero-emission vehicles (ignoring the energy costs of manufacture), and an advance towards reducing greenhouse gas emissions can be accomplished. This is brought out clearly in Figure 3.

28 Sioshansi, R. and Denholm, P. 2009. 'Emissions impacts and benefits of plug-in hybrid electric vehicles and vehicle-to-grid services', *Environmental Science & Technology* in press.

29 Electric Power Research Institute (EPRI) 2007. *Environmental Assessment of Plug-In Hybrid Electric Vehicles Volume 1: Nationwide Greenhouse Gas Emissions* Technical Report available at http://my.epri.com/portal/server.pt?Abstract_id=000000000001015325.

4. Uptake of Electric Vehicles around the world

There are benefits to be won by the adoption of EVs, and some countries are already leading the charge. China has announced it will be boosting investment in electric and hybrid technology. Other major players – the US, the European Union and Japan – are following suit.



Smart ed at the Brandenburg Gate, Berlin. © 2010 Daimler AG.

Some countries already recognise the significance of the potential changes unleashed by the rapid adoption of EVs and are taking active steps to be leaders in the transition – with benefits flowing from reduced oil dependence, lower greenhouse gas emissions, grid modernisation, cleaner air and lower transport costs. Early leaders, such as China, also recognise that EVs promise the start of a new industrial era that will usher in new industries with significant potential for wealth, employment and enterprise generation.

China

Chief amongst the new players will be China. China's industrial transformation has been dramatic, but it is now about to take another step forward by adopting EVs (with hybrids as the transition) as a major strategic initiative. EVs are good for a latecomer like China because they allow the country to close the technological gap more easily; EVs have simpler engineering and can be built more easily, since they have fewer moving parts than conventional internal combustion engine vehicles. This is the key feature being exploited by late-entrant companies such as BYD, whose plug-in hybrid cars are in essence EVs with a gasoline engine as top-up.[30]

In March 2009 China announced a $1.5 billion boost for Chinese EVs over the next three years – 2009 to 2012. The aim is to produce 500,000 electric and hybrid cars per year by 2011, and it will encourage city governments, airport taxi firms and other fleet operators to take up subsidies on fleets. There are nearly 10 million cars entering China's roads each year – so the 500,000 EVs produced per year will represent just a small fraction. This ratio could grow significantly if cost savings through mass production are substantial.

Both China and the United States governments are protecting their investments in EVs from any cutbacks due to the financial crisis. Both countries see these as essential investments in their automotive future.

BYD stunned the automotive world with its promise to launch an electric car for the United States market in 2011 (a plug-in hybrid).[31] In December 2008 it announced its new lithium iron phosphate battery technology that was two years ahead of its nearest rival, Toyota. We see BYD as an interesting example of the new kind of industrial company that is emerging to take advantage of the transformations that are possible with EVs. BYD has been doubling its EV/battery business each year for the past five or six years. Doubling each year is a considerable achievement. It means that after 10 years the business will have grown 1000-fold – from millions (of dollars, of tonnes, of MW) to billions. This is an unprecedented scale and rate of industrial growth.[32] BYD is the world's largest producer of lithium-ion batteries, and is now building lithium iron phosphate batteries for its automotive products. This is the company's core competence, and it is putting it to good use in becoming China's pre-eminent automotive company in a very short time.

30 See Norihiko Shirouzo 'Technology Levels Playing Field in Race to Market Electric Car', *Wall Street Journal*, 12 January 2009, available at: http://online.wsj.com/article/SB123172034731572313.html.

31 'BYD target US launch for electric cars in 2011', *Gizmag*, 14 January 2009, available at: http://www.gizmag.com/byd-target-us-launch-for-electric-cars-in-2011/10766/

32 It proceeds as follows: 2 (1 year); 4 (2); 8 (3); 16 (4); 32 (5); 64 (6); 128 (7); 256 (8); 512 (9) and 1024 (10).

United States

The Energy Department announced in July 2009 that it is getting ready to provide about $2 billion in grants to create a domestic industry for electric-car batteries; 122 companies are scrambling to take up some of these funds according to the *Washington Post*.[33] The companies that plan to bid for these contracts include:

- *Johnson Controls*, the world's largest maker of lead-acid batteries, applying with Ford Motor to make lithium-ion batteries at a Michigan plant that once made automobile interiors;
- *Dow Chemical*, which has asked for $140 million in grants to scale up production of raw materials for batteries, as well as $550 million to cover about half the cost of setting up plants to manufacture battery packs in Michigan and Missouri. A South Korean company, Kokam, would be a partner in the venture;
- *A123 Systems*, which has developed a lithium-ion battery using its own technology, and which it has developed as a member of the Advanced Battery Consortium in the United States. A123 Systems had sought to win the contract to make batteries for General Motors' Chevy Volt, but GM ultimately opted for lithium-ion batteries from LG Chem;
- *Quallion*, founded in 1998 by biotechnology and aerospace entrepreneur Alfred E. Mann and lithium-ion battery specialist Hisashi Tsukamoto. The company has focused on high-priced niche markets such as custom aerospace uses, medical device implants and battery packs that soldiers can carry more easily on the battlefield.[34]

33 Steven Mufson 'A Jump-Start for New Battery Plants', *Washington Post*, 25 July 2009, available at: http://www.washingtonpost.com/wp-dyn/content/article/2009/07/24/AR2009072403163_pf.html.

34 Grants totalling US$2.4 billion were in fact announced on 5 August 2009. See US Department of Energy Press Release, available at: http://www.energy.gov/news2009/7749.htm.

Japan has one of the longest-standing promotional strategies for electric vehicles and advanced batteries, going back to the 1970s.

European Union

The Directive 2006/32/EC of the European Parliament and of the Council on energy end-use efficiency and energy services includes measures to promote efficient vehicles – including electric vehicles. This was supplemented by the European Union *Energy Security and Solidarity Action Plan* as part of the Community's *Second Strategic Energy Review* (European Union 2008).[35] Individual member countries have also adopted promotional support programs, including the United Kingdom, Portugal and Denmark.

Japan

Japan has one of the longest-standing promotional strategies for electric vehicles and advanced batteries, going back to the 1970s during the first and second oil crises. Its promotion of advanced battery manufacturing, initially for the electronics industry and latterly for the electric vehicles industry (notably hybrids) has spanned research and development support, demonstration programs and market support guided by long-term strategic plans.[36] Toyota leads the Japanese shift from hybrids to plug-in hybrids.

It is clear that around the world there has developed a deep understanding of the industrial possibilities associated with the electric vehicles transformation.

35 European Union 2008. *European Union Energy Security and Solidarity Action Plan: 2nd Strategic Energy Review*, available online at http://ec.europa.eu/energy/strategies/2008/doc/2008_11_ser2/strategic_energy_review_memo.pdf.

36 Ahman, M. 2006. 'Government policy and the development of electric vehicles in Japan' *Energy Policy*, 34 (4): 433-443.

5. New industry developments in Australia

By taking up EVs, a range of opportunities exist for Australian industry. Private companies are already setting an agenda with announcements for roll-outs of EV recharging point networks as early as 2012. Other important opportunities exist in the development of batteries and the shift to renewable resources to help power the new future.

Many commentators are noting the profound impact that EVs are going to have on existing industries, and the opportunities that will be opened up for new industries. McKinsey & Company identify the three most affected as: vehicles; batteries; and electricity utilities. They see both threats in the developments of EVs as well as important opportunities.[37]

a) Electric vehicle infrastructure

We start with a discussion of the charging infrastructure for EVs, partly because this emphasises the systemic nature of the whole development, and also because the Israeli-United States company Better Place is partnering with Macquarie Bank and AGL in Australia to roll out an EV recharging network that is expected by 2012 – third in line behind Israel in 2010 and Denmark in 2011.

Construction of the network of recharging points and battery switching stations is set to begin in 2011, with an operational start date in 2012. By that time the Renault-Nissan Alliance should also be making their mass production EVs such as the Fluence available in Australia – while other producers such as BYD in China should likewise be marketing mass production EVs in Australia. Canberra is targeted as the city where the network will roll out first. Better Place's investment in Canberra will include the installation of charging points in homes, offices, shopping centres and other car parks, where EV owners will be able to plug their vehicles in to be charged. 'Battery Swap Stations' or switching centres will also be built, allowing drivers to swap their depleted lithium-ion battery for a fully charged one.

AGL went on the record at the announcement of this initiative that they would be able to ensure that all cars connected to the grid through the charging network would be able to draw 'clean power', that is, electric power generated from renewable sources. This is an undertaking that everyone in Australia has a stake in monitoring to ensure that it is complied with. But pious words and commitments are not enough. We propose that EVs be introduced in such a way that they will have to be powered from renewable sources – turning AGL's commitment into a public mandate. We discuss how this might be achieved in the Conclusions to this report.

b) Batteries

Batteries are the most obvious of the new industries to be catalysed by the coming EV transformation. Australia has the opportunity to develop all three kinds of batteries, including the supply chains for each. The lead acid battery still has a long life in front of it, particularly if combined with the CSIRO-developed UltraCapacitor, to form the UltraBattery. These types of projects should be receiving substantial funding from the Australian Government's Green Car Innovation Fund.[38]

The NiMH battery is currently the most cost-effective advanced battery for HEVs and PHEVs, and will continue to outperform lithium-ion batteries for some time. Once the NiMH battery patent expires in 2014 the opportunities will open up for renewed competitive dynamics involving NiMH batteries, where Australia should be a player. Again this is a topic on which there should be projects seeking funding from the Green Car Innovation Fund.

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37 McKinsey & Company 2009. 'Electrifying cars: How three industries will evolve', *McKinsey Quarterly*, 2009 No. 3: 87-96.

38 Ausindustry 2009. *Green Car Innovation Fund Factsheet*, available at: http://www.ausindustry.gov.au/Manufacturing/GreenCarInnovationFund/Pages/GreenCarInnovationFund(GCIF).aspx.

There is ample scope for Australian firms to seek to become players in this new competitive space.

Having said this, the world is not waiting around for the NiMH patent to expire. There are other battery technologies under development or production.

The lithium-ion battery (and particularly the lithium iron phosphate version) has considerable potential and could become the battery of the future for EVs. So there is ample scope for Australian firms to seek to become players in this new competitive space – particularly in the value chain from the supply of lithium chloride to lithium carbonate and lithium-ion materials (as explored so far by Galaxy Resources[39]). Again there should be ample scope for funding such proposals under the Green Car Innovation Fund.

Australia has a unique battery technology that could play a useful (if not dominant) role in the world of PHEVs. CSIRO designed the 'Ultrabattery' for HEVs and it is already being made in Japan for supply to Japanese car makers because Japan has a significant HEV manufacturing industry.[40] The battery combines the benefits of supercapacitor technology that absorbs and releases electrical energy rapidly, with the low cost of lead-acid battery technology resulting in a battery around 70% cheaper than the NiMH batteries used in today's HEVs. The Ultrabattery is heavier than the high-tech batteries, but the low cost offers the opportunity to reduce substantially the price premium normally associated with HEVs. As HEVs are introduced to Australia there is an opportunity to introduce at least one Australian technology into the HEV industry. The 'Ultrabattery' is also being tested in wind power applications and is already known to be suitable for automotive applications that need greater energy storage reliability. United States President Obama announced in August 2009 that CSIRO's United States licensee would receive a US$32.5 million grant to further develop the Ultrabattery for applications in electrified vehicles, as part of a large $2.4 billion package of funding for United States battery companies.[41] Its market niche will most likely be in the budget end of the small car market, the heavy vehicle market and stationary energy applications, including uninterruptable power supplies.

Batteries introduced for use in EVs will have to be largely recyclable, partly in response to resource scarcity issues and partly because of the demand that they come with 'green' credentials. We note that there is already in existence an Australian battery recycling initiative.[42] The overhead costs associated with recycling will need to be considered.

Lithium supply issues

The lithium-ion battery does not need metallic lithium, but lithium ion in the form of, say, lithium carbonate, Li_2CO_4. The primary mineral sources for lithium carbonate are saltwater lakes (brine lakes and salt pans) which produce lithium chloride and a hard mineral called spodumene, which is a silicate of aluminium and lithium. The main producers of lithium minerals are Chile, Australia, Argentina, China, Russia and the United States.

Lithium use in batteries expanded significantly in recent years, because

39 'Galaxy Resources announce positive results from Lithium carbonate processing study,' *ABN Newswire*, 28 April 2009, available at: http://www.abnnewswire.net/press/en/60532/Galaxy-Resources-Limited.html and http://www.galaxyresources.com.au.

40 Lam, L.T. and Louey, R. 2006. Development of ultra-battery for hybrid-electric vehicle applications, *Journal of Power Sources*, 158: 1140-1148.

41 See Department of Energy, Press Release, 5 August 2009. 'President Obama Announces $2.4 Billion in Grants to Accelerate the Manufacturing and Deployment of the Next Generation of U.S. Batteries and Electric Vehicles', available at: http://www.energy.gov/news2009/7749.htm.

42 This is the Australian Battery Recycling Initiative (ABRI). ABRI's vision is effective stewardship of all end-of-life batteries. See its website at: http://batteryrecycling.org.au/.

rechargeable lithium batteries were being used increasingly in portable electronic devices and electrical tools. By the end of 2008, global lithium carbonate demand had reached 95,400 tonnes per year, up nearly 3% on the year before; the annual growth rate for global lithium carbonate demand in the past ten years was over 7%. Chile, China and Argentina were the top three countries in terms of lithium carbonate production capacity, and together they were able to satisfy 94% of global lithium carbonate demand. China's global market share increased to 26% in 2007 from 21% in 2006, but the figure declined to 24% in 2008 as a result of natural disasters. China's demand for lithium carbonate has also grown rapidly. Starting from 2008, China entered a releasing period of lithium carbonate productions, i.e. using more than it produced. It is expected that China's annual lithium carbonate output will reach 45,000 tonnes and its production capacity will surpass 60,000 tonnes by 2010.

Meanwhile in Australia the resources company Galaxy Resources (ASX: GXY) is a prominent producer. In January 2009, Galaxy announced its intention to proceed with the development of the Mt Cattlin project, incorporating a 1 million tonne per annum mine and concentrator at Mt Cattlin to produce spodumene and tantalum concentrate. Galaxy Managing Director Iggy Tan said by moving further down the lithium battery supply chain, Galaxy would be able to significantly enhance the value of the Mt Cattlin Lithium-Tantalum project. "By producing our own lithium carbonate we are able to gain greater control over the quality and pricing of the end product," he said in an interview.[43]

The lithium carbonate results indicated that downstream chemical processing is viable, but that the economics of the project could be improved by locating the chemical plant closer to the end markets where there is a cheaper source of acid, soda ash, electricity and consumable costs. It is also expected that establishing a facility in China will require lower capital costs, resulting in a more robust project. Galaxy has commenced the next stage of the study by investigating several sites in China. Other producers include SQM in Chile, Rockwood in Chile and Nevada and FMC in Argentina, as well as numerous companies in China.

Long-term supplies for lithium carbonate should not present particular problems, because reserves appear to be plentiful and in any case the most advanced producers of lithium-ion batteries like BYD are making them 100% recyclable. This is a totally new industrial paradigm, again pioneered in China (the 'Circular Economy'), where zero strain on resources is the key object.

China is handling all relevant aspects of building its national competitive capacity for lithium iron phosphate battery-powered EVs. On the resource supply side, it has an abundance of lithium carbonate resources, and it is bringing forward newly improved means of producing lithium carbonate. On the demand side it is building sources of demand for EVs by tax concessions to encourage their rapid uptake by consumers and fleet operators.

Knowledge flow and capability enhancement is being built through an extraordinary concentration on R&D in numerous laboratories and research institutes. In a report from the United States Argonne National Laboratory, by Pandit Patel, issued in January 2008, it was estimated that China currently employs between 275,000 and 325,000 workers in the battery industry; even allowing for the fact that much of it is labour-intensive, this is still a vast industry already and set to grow much larger as EVs become the major component of new vehicle purchases.[44]

43 *ABN Newswire*, 28 April 2009. Above n 39.

44 The ANL report concludes that "On the whole, the PRC is making vast progress in manufacturing lithium-ion battery technology. The government has a national program in place to attract foreign companies to set up JVs and/or partnerships with Chinese companies. The Chinese government offers large incentives to Chinese companies to produce batteries for export. The Chinese government also gives Chinese-owned companies additional incentives to conduct research and provides capital for manufacturing lithium-ion batteries for all applications." See Patil, 2008, *Developments in Lithium Ion Battery Technology in the People's Republic of China. Report ANL/ESD/08-1*, Argonne National Laboratory, Argonne, Illinois.

If Australia allows the EV market to be dominated by imported EVs without offering a local version, it would be virtually impossible for the local industry to survive.

c) Vehicles

EVs promise a completely new start for the vehicle building industry – as understood by California in relation to Detroit, and by China in relation to Japan and the United States. Conventional internal combustion engine vehicles are exceedingly complex and difficult to design and build, with their thousands of parts and complex subsystems, based on highly complex drive trains involving axles, differential gears, pistons and driving shafts. By contrast, EVs are simplicity itself. A battery powers electric motors which driving wheels; indeed there need be no driving shaft at all, if four electric motors drive four wheels. It is companies like BYD in China that really understand this; they have noted that the EV drastically reduces the entry barriers into the automotive industry, and are taking advantage of this as they shape their strategy.

Australia already has a vehicle manufacturing industry, consisting of automotive majors such as Ford, GM-Holden and Toyota, but extensive supply chain producers as well. Of course this whole complex is geared towards the oil era, and has little capability at the moment for transforming itself to the age of EVs.[46] The reaction of the local car assemblers to the demand for greater fuel efficiency is to pursue alternative liquid fuels, denying the potential to re-invent themselves to address opportunities of the coming EV market. As is the case with every traditional car maker, large investments have been sunk into manufacturing facilities for making car engines and these facilities will be productive for some years yet because the change to EVs cannot happen overnight. However, this is no reason for Australian industry to be left behind as car technology changes. If Australia allows the EV market to be dominated by imported EVs without offering a local version, it would be virtually impossible for the local industry to survive. Initiatives such as the Green Car Innovation Fund should be utilised to promote and accelerate a swing towards EV design, manufacture, servicing and export. This is the next industrial revolution and the Australian industry needs full encouragement to adapt itself to the new demands.

China clearly understands the significance of creating a new vehicle manufacturing industry based on EVs – both all-electric and hybrid-electric vehicles. In the United States, the state of California also understands the significance of the changes created by EVs, which is why the Mayor of San Francisco[47] is such a strong supporter of the ERGO model and brought his city along with other neighbouring cities such as Oakland into a consortium to roll-out the Better Place charging infrastructure after Israel, Denmark and Australia.

d) Renewable energy

The critical factor in reducing greenhouse gas emissions from PHEVs and EVs is the greenhouse emissions intensity of the grid electricity generating system. With the current mix of generation in NSW there is no greenhouse benefit in replacing petrol and diesel-fuelled vehicles with PHEV and EV. In Victoria there would actually be a 30% increase in emissions as electricity is generated from brown coal in that state. Only in Tasmania, with hydroelectricity as its principal source of electricity, would there be substantial benefit.

Once EVs enter the equation, existing studies of the take-up of renewable energies will need to be updated. There are several low-emissions energy scenarios for Australia's electricity generating system. For instance, Saddler,

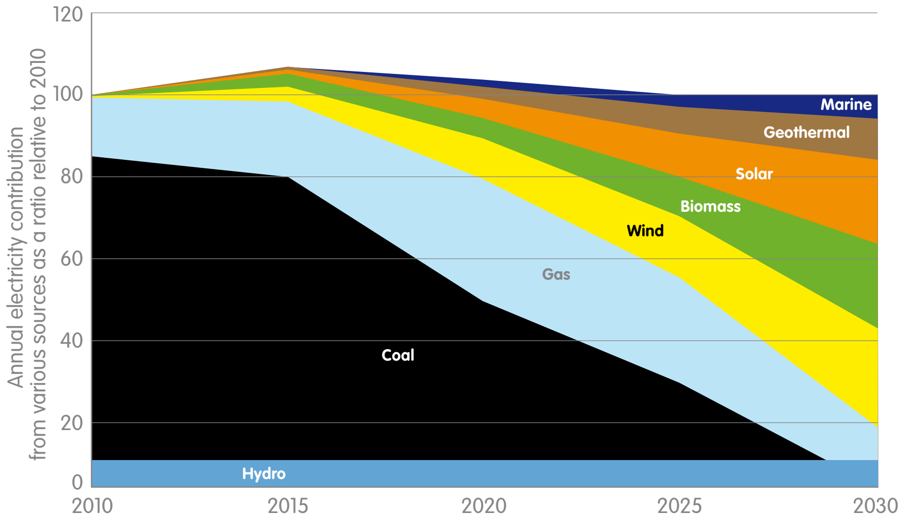
46 It is worth pointing out that there are a couple of very small Australian companies offering conversion options to electric vehicle status, namely Blade Electric Vehicles cars (using Hyundai Getz). See the company's website at: http://www.bev.com.au/; and Energetique (using Mazda 2), see http://www.energetique.com.au/.

47 Andersen, P.H., Mathews, J.A. and Rask, M. 2009. Above n 13.

Diesendorf and Denniss (2004, 2007)[48,49] developed scenarios for cutting greenhouse gas emissions from stationary energy to 50% below the 2001 level by 2040. Since the scenarios were based on small improvements to existing technologies, high-temperature heat had to be supplied by natural gas and almost all of the emission reductions were achieved through energy efficiency and electricity generation. A scenario by McKinsey and Company (2008)[50] found that a reduction in Australia's CO_2 emissions to 30% below the 1990 level is achievable by 2020 and that 60% below the 1990 level could be reached by 2030. It found that the 2020 reduction was affordable, with the cost savings from efficient energy use paying for a large proportion of the additional costs of cleaner energy supply.

Leading climate scientist James Hansen has argued that the key element in reducing greenhouse gas emissions is the need to phase-out all conventional coal-fired power stations by 2030.[51] Since neither carbon capture and sequestration nor nuclear power is likely to be ready to make a significant reduction in emissions before 2025 or 2030;[52,53] the main task in achieving Hansen's target has to be met by efficient energy use and renewable energy. A notional scenario, based on the studies cited in the previous paragraph, is shown in Figure 4, where the various renewable energy sources are shown with emissions at 2010 set at 100.

Figure 4. A renewable electricity scenario for Australia, 2010–2030



Source: Diesendorf, private communication, based on updates of Saddler, Diesendorf & Denniss (2004)[54] and Diesendorf (2007b).[55]

In this notional future, growth in electricity generation peaks in 2015, mainly as the result of rigorous implementation of efficient energy use. Meanwhile, to achieve such a future will require the building of new kinds of businesses and factories, with professionals and tradespeople trained with new skills for the transition. Between 2010 and 2020, the principal renewable energy sources that are commercially available on a large-scale are wind and biomass. The latter could be based either on direct combustion or gasification and then combustion of residues of existing crops (wheat, sugar) and plantation forests. Together with gas, these are the principal new electricity supply technologies. They can buy time for the less developed and more expensive technologies – solar photovoltaic modules, concentrated solar thermal power, hot rock geothermal power and marine (wave and ocean current) power, all of which could make very substantial contributions post-2020.[56,57]

It is worth pointing out that in the United States, new electric capacity each year shifts more and more towards renewable sources – so much so that by the year 2008 new capacity was sourced more than 50% from renewables, mostly wind power.[58] In Europe in 2008, wind power contributed the largest increase in electricity generating capacity of all sources, including coal, gas and nuclear. We would like to see a comparable calculation made for Australia to act as benchmark as we begin the shift towards the EV transformation and with it, the potential shift to renewable sources for electricity generation.

48 Saddler, H., Diesendorf, M. and Denniss, R. 2004. *A Clean Energy Future for Australia*, Clean Energy Future Group, Sydney.

49 Saddler, H., Diesendorf, M. and Denniss, R. 2007. Clean energy scenarios for Australia, *Energy Policy* 35(2): 1245–56.

50 McKinsey & Company 2008. *An Australian Cost Curve for Greenhouse Gas Reduction*, available at http://www.mckinsey.com/clientservice/ccsi/pdf/Australian_Cost_Curve_for_GHG_Reduction.pdf.

51 Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., Pagani, M., Raymo, M., Royer, D. and Zachos, J. 2008. 'Target atmospheric CO_2: Where should humanity aim?' *Open Atmospheric Science Journal* 2: 217–31.

52 Saddler, H., Riedy, C.J. & Passey, R. 2004. 'Geosequestration: what is it & how much can it contribute to a sustainable energy policy for Australia?' *The Australia Institute Discussion Paper*, vol. 72: 1-62.

53 Diesendorf, M, 2007a. *Greenhouse Solutions with Sustainable Energy*, UNSW Press, Sydney.

54 Saddler, H., Diesendorf, M. and Denniss, R. 2004. Above n 48.

55 Diesendorf, M. 2007b. *Paths to a Low-Carbon Future: Reducing Australia's greenhouse gas emissions by 30 per cent by 2020*, Greenpeace Australia Pacific, September 2007.

56 Ibid.

57 Diesendorf, M. 2009. *Climate Action: A campaign manual for greenhouse solutions*, UNSW Press, Sydney.

58 See The Prometheus Institute, March 25, 2009. 'New electric capacity in US shifts to renewables' Renewable Energy Industry. Available at: www.prometheus.org.

6. Conclusions and recommendations

The EV revolution heralds a change in the way we use the resources around us, just as the Industrial Revolution did two centuries ago. The transition to a transport future defined by the EV is not just necessary, it is inevitable. It remains for industry and governments Australia-wide to show us the way.

Our conclusions and recommendations are relatively simple. We propose that EVs be viewed as a general-purpose technology that will have system-wide changes – like steam engines, railways and electricity itself in earlier phases of industrial evolution. We view EVs as impacting on electricity grid design and operation, on battery industrial evolution and automotive evolution, on the uptake of renewable energies and on reductions in greenhouse gas emissions. Our recommendations are designed then to capture these over-arching effects and help to bring them together, each one catalysing and building on the effects of the others.

Chief among our recommendations is that someone in the Australian Government takes overall leadership of the EV revolution, to become the promoter and head negotiator with other parts of government and with the private sector in paving the way for the rapid introduction of EVs. This can be justified on national security grounds, since EVs are going to save Australia oil imports, reduce energy insecurity, reduce greenhouse gas emissions if implemented in an appropriate way, and ultimately make Australia less vulnerable to oil-related threats (see Jamison *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia* 2010).

Our policy recommendations concern the following specific issues, all of which need to be addressed in order to facilitate the coming energy and transport EV revolution. Our recommendations are for a holistic approach to smoothing the transition to EVs, seeing this transition as inevitable but possibly retarded by unnecessary administrative delays as regulatory frameworks for a fossil fuel era block the advent of the EV era.

1. Electrification of transport as a goal with a consequent reduction of oil dependency where electricity is supplied from renewable sources;

2. Laying down of EV infrastructure;

3. Redesigning and re-regulating the electricity grid to meet future needs and capitalising on opportunities presented by a growing population of EVs. This includes legislation about power supply sources (such as renewables and home-generated power), modernisation of the grid and deciding on grid-balancing issues such as time periods when re-charging is permissible or optimal;

4. Promotion of consumer take-up of EVs, conditional tax concessions and adoption of EVs by fleets;

5. Promotion of industries linked to EVs – vehicles, batteries, infrastructure, renewable energies, smart grid software;

6. Promotion of renewable energy sources, and means for bringing them on stream more rapidly;

7. Promotion of hybrid vehicles as an interim measure;

8. State and city-wide initiatives such as implementation of recharging standards and public education;

9. Research conducted that incorporates economic as well as sociological factors including new skills development and transitioning workers from traditional automotive industry to EV production.

The bias towards fossil fuelled transport, which is present in tax policies, regulations and the attitudes of business, needs to be changed.

1. Electrification of transport

Electrification of transport used to mean the slow take-up of electrified public transport (and even then we have only gone a little way down the track in Australia, with urban rail overcrowded and failing to meet demand in several cities and with inter-city rail transport still largely diesel-powered). Improvements in the infrastructure and service frequency of urban rail should become a priority. Now with EVs on the horizon electrification has taken on an additional important meaning. Now the bias towards fossil fuelled transport, which is present in tax policies, regulations and the attitudes of business, needs to be changed.

In the name of national security, energy security and reduced dependence on oil, we should be pressing for an over-arching bias in all government policies and regulations towards promoting the uptake of EVs, the further electrification of transport generally (see Jamison *An Alternative Fuel and Technology Mix for Passenger Vehicles in Australia* 2010) and the critical development of renewable energy sources to power the emerging EV fleet. The different approaches adopted in other countries (as discussed above) can serve as guides.

Neither Denmark nor Israel has an existing vehicle building industry. Yet they are promoting the take-up of EVs through a range of taxes and other incentives. In Israel there are differential taxes governing the purchase of new cars, with EVs enjoying at least a 50% advantage over internal combustion engine vehicles. In Denmark likewise there are substantial tax advantages in place to favour uptake of EVs. China was discussed above as a place where there are substantial tax concessions and other incentives designed to drive the uptake of hybrids and EVs.

Yet in Australia at this point there are no regulatory provisions favouring EVs. This is what we suggest has to change initially. We need a countdown to the EV revolution with government ministers (Energy and Resources, Industry, Environment, Climate Change) being held accountable and required to report progress in their various portfolios to adapting the regulatory framework to facilitate the arrival of EVs.

It may be that many car buyers will opt for cars that have an on-board, oil-fuelled, small engine as a range-extender, to provide the security of being able to travel further without recharging their batteries. If this were so, we are convinced that the incentive will be to use electrical power in preference to oil power because oil is unlikely to be cheaper today than in the coming decades, while electricity is likely to become cleaner in terms of greenhouse gas emissions. The Green Car Innovation Fund could be used to promote EVs in similar ways to those being used in Denmark and Israel. This is subsidising green purchases in order to kick-start the industry in this country.

2. Laying down of electric vehicle infrastructure

An infrastructure to support EVs is needed to make Australian cities and inter-city arterials 'EV-ready' – as promoted by Better Place in Australia, eTec in some states in the United States and EDF in France.

The Better Place approach in Australia has so far received the support of the Victorian Government. But really it needs the full support of the Australian Government, of state and territory governments (including the ACT where Better Place has announced it will target its first full roll-out of urban charging points) and of city councils. This is necessary in order to demonstrate

a commitment to future technological progress and prosperity, as well as a determination to overcome administrative and bureaucratic obstacles that will almost certainly be encountered as the new EV infrastructure is developed.

If EVs are really intended to run on renewable energy, then charging points and battery exchange stations must have mandatory 100% Green Power. This entails that the physical connection between vehicle and grid through a standard power point (possibly using coal-fired electricity) must be discouraged – through stringent incentives and disincentives, as we discuss further below.

3. Redesigning and re-regulating the electricity grid

The roll-out of new G2V and ultimately V2G infrastructure will involve a complete overhaul of the grid itself and of the regulatory framework governing the distribution of electric power – from planning permits in city commercial areas to allow public access charging points to be erected, to the rules under which the entire grid operates. We recognise that to stimulate the modernisation of the grid and to facilitate the supply of power from renewable energy sources, gross feed-in tariff arrangements will be needed, providing for households and larger renewable energy power stations to be paid premium rates for all renewable electricity they supply to the grid.

The current electricity grid is on the one hand a great resource for EVs – in that it exists and can be tapped almost anywhere in the country – but on the other hand it is an antiquated and unintelligent resource that drastically needs to be upgraded. The arrival of EVs will make this a necessity, since infrastructure companies will want to use grid intelligence to even out their demands on the electrical grid (to iron out demand and prevent 'peaking') and to allow drivers to choose convenient charging points and convenient times for charging. We are encouraged that there is already dialogue on this topic between Better Place and AGL in Australia, with a view to setting standards for G2V and V2G initiatives. We also need to hear governments announcing their full support for such initiatives. The arrival of EVs promises a once-in-a-century opportunity to modernise the grid and to increase the penetration of renewable energy into the grid.

In order for EVs to be part of a 'smart grid' system, they will have to be plugged in to a high amperage circuit (with appropriate safeguards), as feeding back any significant amount of power from the vehicle battery to the grid will require much higher power capability than a household circuit (max. 2.4 kW). We are not in a position to recommend whether this should be three-phase or a high amperage single-phase system. On this matter we need specific input from the power suppliers. The wider policy point is that public recharging points need to be supplied with power through a dedicated circuit that can be guaranteed (and audited) to provide power from renewable sources only. This is the key to ensuring that EVs drive the adoption of renewable energy, rather than ending up exacerbating the production of electric power from fossil fuel sources.

4. Promotion of consumer take-up of electric vehicles and adoption by fleets

Promotion of EVs should start with their adoption by fleets, particularly taxis in each of the major cities, as well as large government fleets (Commonwealth, state-level and municipal) and commercial delivery vehicles. Incentives in terms of taxes, registration and GST need to be tailored so that fleets will preferentially switch to EVs – thus setting the example that will be followed by non-fleet purchasers. It is a matter of the highest national importance that we switch to electrified transport powered by renewable energy and vital to national security that we reduce our dependence on oil and other fossil fuels.

Fleets such as taxi and government vehicles should be targeted first, city by city. The city of Sydney could target the taxi fleet operated, for example, by Taxis Combined Services (the largest fleet operator linked to Cabcharge). Other cities could likewise target their major taxi fleets, offering substantial financial incentives to renew them with EVs – initially hybrids and then moving to all-electric vehicles. Swinging a taxi fleet to EVs could be a priority, and involve lobbying at the city level, the state level and the federal level. At the federal level there could be group financial incentives included in an Omnibus Promotion of EVs Act. At the state level there could be financial incentives linked to reduced registration charges. The city level is discussed below.

When it comes to adoption of EVs by consumers generally, care must be exercised in the framing of recommendations. If we give the go-ahead for all users of EVs and PHEVs to charge their vehicles at home, without any requirement that the electricity utilised come from renewable sources, then the level of greenhouse gas emissions would actually rise – a perverse outcome. If, on the other hand, we recommended that home charging be disallowed, this would remove one of the key inducements to purchase an EV in the first place, and make load balancing by utilities more complex. So we wish to steer a middle way, between encouraging use of renewable energy sources and mandating them to the exclusion of everything else.

One way of achieving this result is to provide EVs with conditional tax credits. The purchasers of EVs would be able to claim a substantial tax credit in return for certifying that they are utilising green electricity sources for their home charging. These could come from their own home generation systems (solar or wind-based), or from their specifying green sources from their electric utility company. Vehicle owners unable to provide such certification would not be able to claim the tax credit. This provision could be supplemented by a requirement that all public recharging points utilise dedicated electric power circuits that are guaranteed to be fed from renewable sources (as discussed in [3] above).

> Australia can choose to follow its usual practice of waiting for the rest of the world to gear up for the new industries being spawned by the EV revolution or we can take some initiatives now while the field is still relatively new.

Consider the case of state-level car registration, which is in effect a tax on car ownership. One way forward would be for state governments to reduce car registration charges to zero for EV purchasers, provided they could supply a Green Electricity Certificate along with their pink slip (to certify road worthiness) and green slip (to certify third party insurance). This would not be an onerous extension of present requirements. Car registration charges for non-EVs could be maintained at their present levels (to create a differential) and state governments be compensated for the difference out of the proposed cap and trade system (the Carbon Pollution Reduction Scheme) or an alternative carbon tax. Another way would be for EV purchasers to supply electricity bills showing 100% Green Power at registration. Battery exchange systems would call for separate treatment involving certification of batteries used by the battery exchange company to ensure they are be charged from renewable energy sources.

5. Promotion of industries linked to electric vehicles – vehicles, batteries, infrastructure, renewable energies, smart grid software

Australia can choose to follow its usual practice of waiting for the rest of the world to gear up for the new industries being spawned by the EV revolution – new vehicle building industries, new battery producers, new infrastructure producing industries, new software producing industries for the smart grid and connected vehicles – or we can take some initiatives now while the field is still relatively new and get in early to build the new industries that will inevitably take over from the old. There is every reason for Australia to do the early research in how best to capitalise on this new set of technologies. Australia will have to adapt overseas experience to local conditions. Distances, infrastructure and the transport mix are not the same as anywhere else and the market left to its own devices is not likely to yield an optimum system.

The existing grid is geared to producing electricity from a small number of generating sites, such as the Latrobe and Hunter Valleys. Tomorrow's grid must be capable of accepting large quantities of wind power from South Australia, hot rock geothermal power from Central Australia, bioelectricity from rural centres, large-scale solar power from everywhere west of the Great Divide, small-scale solar photovoltaic power from residential rooftops and power from millions of EVs.

Australia can choose to take advantage of the introduction of EVs to mandate their usage of renewable energy, placing the onus on electric power generators and distributors to ensure that they access sufficient sources of renewable energy to meet the growing demand from EVs. A simple market mandate with conditional tax credits (e.g. that all demand for power for EVs be met by renewable sources) would transform the energy landscape in Australia. If linked to IT intelligence then such extra demand could be met by reducing peak flows, without the need for extra sources (and, in particular, without the need for extra fossil-fuelled sources). This is clearly the optimal pathway through which EVs should be introduced to Australia.

Renewable electricity – especially wind, large-scale solar and hot rock geothermal power – needs new transmission lines to deliver power from regions of high resource to consumers.

6. Promotion of renewable energy sources, and means for bringing them on stream more rapidly

Firms like AGL are committing themselves to bringing renewable electricity sources on line as fast as possible, so that drivers can recharge their EV or hybrid in full confidence that the power is being generated from renewable sources. These commitments need to be backed by a whole-of-government approach to accelerating the uptake of renewable energy sources – especially solar, wind, geothermal and bioenergy – and the phasing out of fossil fuel sources without the capacity to mitigate greenhouse gas emissions, such as coal – as advocated in our first Jamison report (2008).

To facilitate the growth of renewable electricity supply, we welcome the long-awaited Expanded Renewable Energy Target (RET) of 20% of electricity to be generated from renewable sources by 2020. We note, however, that under the present design, it is likely that most of the target will be met by a combination of solar hot water and 'phantom' renewable energy certificates that do not represent actual renewable electricity generation. At best this target will only offer modest assistance to the lowest cost of the large-scale renewable electricity source, namely wind power. Separate policies, in the form of a national gross feed-in tariff scheme are needed to encourage the expansion of residential generation of renewable electricity, large-scale solar power, bioenergy and hot-rock geothermal power. This scheme would be similar to the successful schemes in Europe. It would pay premium prices for all renewable electricity fed into the grid, with different prices for different renewable electricity technologies, depending upon their needs. If the flaws in the Expanded RET are not fixed, we recommend that large-scale wind power be included in the national feed-in tariffs and then removed from the RET.

Renewable electricity – especially wind, large-scale solar and hot rock geothermal power – needs new transmission lines to deliver power from regions of high resource to consumers. We recommend that these be funded as national infrastructure.

To further encourage a shift away from coal power, a carbon price is needed. Unfortunately the small greenhouse target combined with the design of the proposed emissions trading scheme, known as the Carbon Pollution Reduction Scheme (CPRS), is unlikely to be effective in reducing Australia's emissions. The purpose of an emissions trading scheme is to increase the price of greenhouse-intensive industries and products, making the polluter pay and thus encouraging a shift in the economy to cleaner industries and products. Under its present design CPRS fails to do this, because it offers free emission permits to the biggest greenhouse polluters and allows the medium-level greenhouse polluters to offset all their emissions overseas in schemes of dubious effectiveness. We recommend that either CPRS be reformed to make it effective or be replaced with a carbon tax. In the interim, we recommend that federal and state governments ban new conventional coal-fired power stations and extensions to existing ones.

7. Promotion of hybrid vehicles as interim measure

Given that it will take several years to establish the infrastructure for all-electric vehicles, a start should be made in getting Australia EV-friendly through active promotion of hybrids – through all the mechanisms outlined above, including uptake of hybrids by fleet operators such as taxis and state and Commonwealth vehicles operators.

8. State and city-wide initiatives

A host of state-level laws and regulations stand as barriers to the adoption of EVs or simply provide no guidance where guidance is needed. For example there are no standards currently existing for the provision of charging and recharging points, with open standards that are compatible with initiatives being taken by car manufacturers and by infrastructure providers. We recommend that governments and interested parties such as motoring organisations stage conferences and working parties where these issues may be canvassed and recommendations framed.

9. Research must be conducted that incorporates economic as well as sociological factors

It is vital that research is conducted to determine the economic and sociological impacts involved with the delivery of an entirely new form of mobility and energy management choices. There are considerable training, servicing and displacement issues associated with the rise of a new technology and demise of the old. These issues present significant management challenges to facilitate the re-skilling and transitioning of the current labour force to maximise the success of the transition and to ameliorate the social and economic difficulties that may be faced.

Final remarks

Australia's energy, automotive and transport industries are still completely locked into the fossil fuel age. For fuels we produce only oil and gas – and only a tiny proportion of the gas goes towards transport. For cars, apart from the new Toyota Hybrid Camry, we produce only petrol and diesel-burning models. For batteries, we produce only lead-acid batteries for use in traditional vehicles. We don't produce lithium iron phosphate batteries, which are emerging as market leaders for the EV sector, nor do we produce NiMH batteries as used in hybrid vehicles.

Our automotive industry is geared entirely towards the production and maintenance of petroleum – or natural gas-fuelled vehicles – perhaps with a tiny proportion of biofuels. Our energy production systems are geared towards coal and its export. Our vehicle fleets are overwhelmingly driven on internal combustion engines.

Yet within the decade the dominant trend is likely to be towards new EVs including hybrids, new lithium-ion batteries, new infrastructure such as multiple charging points to complement the existing petrol station structure, and new renewable energy sources to clean up our electricity supply system and power vehicles. The question we have to ask is: To what extent will these elements be provided by products and services produced in Australia, and to what extent will they simply be imported, with the new industries being encouraged overseas but not here in Australia? We have to ask whether breakthroughs will be called for, led by imaginative and far-reaching initiatives.

This is the challenge – and the opportunity – posed by the electric vehicle revolution.

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Acronyms

BTL	Biomass-to-liquid conversion
BTU	British Thermal Unit
CCS	Carbon capture and sequestration
CHP	Combined Heat and Power
CNG	Compressed natural gas
CTL	Coal-to-liquid conversion
ERGO	Electric Recharge Grid Operator
EM	Electric Motor
EVs	Electric Vehicles
FTS	Fischer Tropsch Synthesis
GTL	Gas-to-liquid conversion
G2V	Grid to Vehicle
GCIF	Green Car Innovation Fund
GHGs	Greenhouse Gas emissions
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
LFP	Lithium Ferrous Phosphate battery
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
NiMH	Nickel Metal Hydride battery
PHEV	Plug-in Hybrid Electric Vehicle
RNA	Renault-Nissan Alliance
V2G	Vehicle to Grid
VPP	Virtual Power Plant
ZEV	Zero Emission Vehicle

Conversion units

Volumes

3.79 litres = 1 US gallon

159 litres = 1 barrel of oil = 6×10^9 J

1 litre of gasoline = 0.34×10^8 J

1 cu foot = 2.83×10^4 cm^3

1 PJ/annum= 31 MW

Efficiencies

1 mile per gallon (US) = 0.42 km/L = 235 L/100 km

10 miles per gallon = 2.4 km/L = 23.5 L/100 km

Passenger vehicle (petrol) with fuel consumption of 10 L/100 km emits 282 g CO_2/km

Metric prefixes

k	kilo	10^3 (thousand)
M	mega	10^6 (million)
G	giga	10^9 (billion)
T	tera	10^{12}
P	peta	10^{15}

Areas

1 hectare = 10,000 square metres = 2.47 acres

100 hectare = 1 square kilometre

1 is equivalent to	Joule	Calorie	BTU	kilowatt-hr	horsepower-hr	Ergs
Joules	1.0	4.2	1.1×10^3	3.6×10^6	2.7×10^6	1.0×10^{-7}
Calories	2.4×10^{-1}	1.0	2.5×10^5	8.6×10^5	6 with the $.4 \times 10^5$	2.4×10^{-8}
BTUs	9.5×10^{-4}	4.0×10^{-3}	1.0	3.4×10^3	2.5×10^3	9.5×10^{-11}
Kilowatt-hrs	2.8×10^{-7}	1.2×10^{-6}	2.0×10^{-4}	1.0	7.5×10^{-1}	2.8×10^{-14}
Horsepower-hrs	3.7×10^{-7}	1.6×10^{-6}	3.9×10^{-4}	1.3	1.0	3.7×10^{-14}
Ergs	1.0×10^7	4.2×10^7	1.1×10^{10}	3.6×10^{13}	2.7×10^3	1.0

1 is equivalent to	Coal (t)	Lignite (t)	Crude petroleum (t)	Crude petroleum (barrel)	Natural gas (m^3)	kilowatt -hr	Joule
Coal (t)	1.0	0.5-0.7	1.3	1.9×10^{-1}	1.3×10^{-3}	1.3×10^{-4}	3.5×10^{-11}
Energy (J)	2.88×10^{10}	$1.4\text{-}2.0 \times 10^{10}$	3.7×10^{10}	6×10^9	3.8×10^7	3.6×10^6	1.0

Definitions

Biofuel: Fuel manufactured from plant material derived from cultivated or natural vegetation, in which the energy of solar radiation captured by the photosynthetic process in carbohydrate or oil compounds is made available for use as a source of energy.

Bioethanol: Ethanol produced by the fermentation of plant materials.

Biodiesel: Diesel produced by the conversion of plant material.

1st generation biofuel: Fuel produced from crops including corn, wheat, sugar and canola that, when fermented, produce bioethanol.

2nd generation biofuel: Fuels based on non-food crops/products such as cellulose materials, wood products or non-edible, often waste, products from existing agricultural or forestry activities that are fermented to produce ethanol or gasified to produce syngas from which liquid fuels can be produced.

Blendstocks: Any input material that is used as a mixture to make a product.

Boe (Barrels of oil equivalent): A unit of energy that approximates the energy released in the combustion of one barrel (159 L) of crude oil, i.e. 6.1 GJ.

Coal-to-liquids (CTL) technologies: Coal can be converted into liquid fuels by several different processes. They involve carbon dioxide (CO_2) emissions in the conversion process meaning that the greenhouse gas footprint of these fuels (unless accompanied by carbon capture and sequestration) is generally greater than those of liquid fuels.

Compressed natural gas (CNG): Made by compressing natural gas to less than 1% of its volume and stored in cylinders at pressures between about 200–220 bar.

Diesel: A liquid fuel composed of a mixture of hydrocarbons and used in compression-ignition engines.

Dimethyl ether (DME): An organic compound (CH_3OCH_3) that is a colourless gas that can be used as a clean-burning fuel. Produced by converting hydrocarbons, predominantly sourced from natural gas (or to a lesser extent the gasification of coal) to produce syngas. Syngas can be catalytically converted into methanol.

Ethanol (ethyl alcohol): An organic compound (C_2H_5OH) that can be use as a liquid fuel made from the fermentation of plant sugar and starches or hydrolysed cellulose and hemicellulose, or from fossil feedstocks.

Energy density: The energy context per unit of volume of a liquid fuel, or it can refer to the energy content per unit volume or mass of a battery system.

Fischer Tropsch Synthesis (FTS): A catalyzed reaction where a mixture of carbon monoxide and hydrogen is converted into liquid hydrocarbons.

Gas-to-liquids (GTL) transformation: The process for converting natural gas to gasoline, diesel and other transport fuels.

Gasoline: See Petrol.

Liquefied petroleum gas (LPG): A fossil fuel derived from the processing of crude oil and natural gas and comprised principally of propane (C_3H_8) and butane (C_4H_{10}). It exists as a liquid under moderate pressure occupying about 1/250th of its volume as a gas.

Liquefied natural gas (LNG): This is gas that occurs naturally associated with coal seams. It is predominately methane (CH_4), which is processed to remove a range of trace hydrocarbons and other trace compounds including relatively large amounts of carbon dioxide before compression for transportation as a liquid. Carbon dioxide released in the process of gas purification can be a significant part of the total greenhouse gas emissions related to this energy source.

Methanol (CH_3OH; methyl alcohol): A compound found naturally in the environment as a result of anaerobic metabolism. In significant volumes it can be used as a liquid fuel in its own right as an additive to petroleum.

Net Primary Production: The biomass produced by a plant or ecosystem over a period of time (say a year) by virtue of photosynthetic activity, less the biomass metabolised by the plant or ecosystem for its own maintenance.

Petroleum: Generic term for all hydrocarbon oils and gases, including refined petroleum products.

Petrol (gasoline): A mixture of hydrocarbons used in spark ignition engines.

Synfuels: Liquid and gaseous fuels obtained from coal, natural gas or biomass via the Fischer Tropsch process, fermentation of coal gasification.

Syngas: A synthetically formed mixture of carbon monoxide, hydrogen, methane and carbon dioxide formed during the heating of biomass and its gasification.