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# The (green) car of the future

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## Contents

## Acknowledgements

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# Executive summary

'Motorcars produced this year will run into millions—no doubt they will' WGP.

'The problem with automatic cars is that they're still being driven by manual brains'. P K Shaw.

A panacea for the environmental problems of modern motor vehicles – especially their use of non-renewable oil and their emissions – has long been the subject of speculation. Various alternative fuels are put forward as solutions to the world's diminishing reserves of oil, but each seems to have its own issues and problems to deal with, not to mention effects on agricultural crops previously destined for human food consumption. Meanwhile, the use of natural gas and biogas appear as feasible interim solutions to fuel shortages, but the pressure continues to reduce greenhouse gas emissions, so that the 'holy grail' of vehicle fuels is to achieve a carbon-free status. One possibility is the use of hydrogen, but this remains elusive.

Hybrid vehicles may provide some limited efficiencies, but tend to initially cost more to buy which negates their perceived advantage. Various hybrid types have been produced or are under investigation with the latest trend being toward plug-in varieties that seem to combine the benefits of electric cars with an engine in reserve. Electric vehicles have a long history of development but suffered from range and safety problems, which have only recently been addressed with new nanotechnologies. Other options, like compressed air cars and hydrogen concepts, seem to have a way to go for acceptance by the vehicle industry, consumers and driving commentators.

Australia has a role to play in assessing such advanced technologies, with past experience in developing concept hybrid cars and new projects. While the Government has proposed grants for hybrid production, other regulatory areas such as safety standards can prove burdensome for new entrants. Infrastructure development can also be a huge hurdle for the introduction of new car systems such as alternative fuel supplies. Nonetheless, Australia's part in the global automobile manufacturing industry is just a small niche player, but perhaps with a potential to be influential.

# The dream car

Humanity's love affair with the 'internal combustion engine on wheels' is a long saga that demonstrates that not much has actually changed, despite the whims and wishes of consumers and manufacturers. Indeed for Australia, the University of Sydney Warren Centre project on *Sustainable Transport in Sustainable Cities* notes our marriage with the car:

> Personal mobility is synonymous with the ideals of freedom, individuality and personal choice and currently the motor vehicle provides all these virtues at the levels of safety, comfort and fashion that people desire.[1]

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1. Warren Centre for Advanced Engineering, *Sustainable transport in sustainable cities: moving people*, University of Sydney, July 2002.

The 14.8 million vehicles registered in Australia travelled more than 215 billion kilometres in the 12 months ended 31 October 2007, according to figures released by the Australian Bureau of Statistics.[2] Passenger vehicles accounted for 73 per cent of the distance travelled (158 billion kilometres). More than half (51 per cent) of the distance travelled by passenger vehicles was for personal and other use, with 29 per cent for travel to and from work, and 20 per cent for business use. Clearly changing the makeup of the local vehicle fleet is an enormous task. So there are around 15 million motor vehicles on the road here with passenger cars and sports utility vehicles (SUVs) comprising over three-quarters of the vehicular fleet.

The average age of the passenger fleet is almost ten years and so any plans to replace vehicles with more efficient types has to consider the low replacement rate of about 10 per cent per annum. Australian-made passenger vehicles comprise only about 10 per cent of the new vehicle market nowadays. Motorcycles and scooters (around some three per cent of all vehicles) have a fuel efficiency advantage over most passenger vehicles, but safety and practical issues restrict their wide use on Australian roads.

This paper provides an overview of the types of alternative technologies under investigation to provide for the vehicles of the future. It should be noted from the outset that laws of physics dictate some form of energy to provide motive force to propel vehicles. In general, all of the types of vehicle technology involve energy input either in terms of fuel or electrical energy supply from an external source. The first part of the discussion introduces the history of various alternative vehicle types before later discussing hybrid vehicle options to use alternative fuels, electric, compressed air and hydrogen vehicles, and Australia's outlook.

A more recent consideration is to find ways of making vehicles more fuel efficient and "greener" in terms of reducing emissions and pollutants, and enabling means of more sustainable vehicle and fuel manufacture. These factors include consideration of ways to:

- reduce emissions of pollutants of concern to human and ecosystem health—e.g. carbon monoxide (CO), nitrous oxides (NOx), polycyclic aromatic hydrocarbons (PAHs), unburned hydrocarbons (HCs), benzene and other air toxics, and particulates. Such a reduction would improve local air quality (and could also minimise photochemical smog)
- reduce emissions of carbon dioxide ($CO_2$), as an anthropogenic greenhouse (GH) gas
- use renewable and sustainable energy sources rather than finite and diminishing ones and
- be built of materials that are either recyclable, renewable, or readily degradable.

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2. Australian Bureau of Statistics (ABS), *Vehicles in Australia travelled over 215 billion kilometres in 2007: ABS*, news release, ABS, 28 August 2008, viewed 8 July 2009, http://www.abs.gov.au/AUSSTATS/abs@.nsf/mediareleasesbyReleaseDate/6006BF6A6CC2F525CA2574B20020D2AB?OpenDocument

## Fuel efficiency

It is possible to help with the first two factors mentioned above by simply improving efficiency of individual vehicles, but only if the total vehicle fleet does not continue to grow. However, change is slow and the basic configuration of the motor vehicle has not altered a great deal over the past century. In fact with the addition of safety features and comfort add-ons, there has been no real gain in average fuel efficiency over the last few decades.[3] In September 2008, the Australian Transport Council (ATC) released a Public Discussion Paper on *Vehicle Fuel Efficiency: Potential Measures to Encourage the Uptake of More Fuel Efficient, Low Carbon Emission Vehicles* which noted the slow change, stating in part that:

> The average fuel consumption of all light vehicles has hardly changed over the last decade. Engine technology in terms of fuel consumption per power output has improved substantially and there has been an improvement in fuel efficiency in the new passenger vehicle fleet. However, potential fuel savings across the whole light vehicle fleet have been offset by increases in vehicle power, size and weight, by the strong growth in sales of four wheel drive sports utility vehicles (SUVs), and increases in the fuel consumption of light commercial vehicles.[4]In Australia, petrol is by far the main passenger vehicle fuel; vehicles using diesel fuels range from one per cent of older types to around four per cent of newer models. The only other significant alternative fuel is liquid petroleum gas (LPG) use at around three per cent. Diesel vehicles exhibit some fuel efficiency and performance savings over petrol models as diesel fuel has around 10 to 20 per cent more energy per unit volume than petrol, to provide a reduced fuel consumption for a given power of 25 to 30 per cent.[5].

The ATC paper compares various potential measures to encourage the uptake of more fuel-efficient, low carbon emission vehicles. The paper notes that there are national schemes that foster improved fuel efficiency and car manufacture innovation. As well, Australia has had a number of national level programs which do not have improved fuel efficiency or lower $CO_2$ emissions as their primary objective, but do have some influence on these objectives.

In May 2009, the President of the United States announced the proposed introduction of tighter fuel efficiency and emission standards for American vehicles. The standards would aim to improve fuel efficiency to 6.63 litres of fuel per 100 kilometres travelled, along with

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3. M Glaskin, 'US vehicle efficiency hardly changed since Model T', *New Scientist*, 23 July 2009, viewed 27 July 2009, http://www.newscientist.com/article/dn17506-us-vehicle-efficiency-hardly-changed-since-model-t.html?DCMP=OTC-rss&nsref=online-news.

4. Australian Transport Council (ATC) and Environment Protection and Heritage Council (EPHC) Vehicle Fuel Efficiency Working Group, *Vehicle fuel efficiency: potential measures to encourage the uptake of more fuel efficient, low carbon emission vehicles*, Public Discussion Paper, ATC and EPHC, Canberra, September 2008, pp. 15–16, viewed 30 June 2009, http://www.environment.gov.au/settlements/transport/publications/pubs/vfe-paper.pdf

5. ATC, pp. 26–27.

concomitant emissions reductions.[6] Australia does not have any national vehicle fuel efficiency standards.[7]

## Alternative fuels in Australia

There are now around a billion motor vehicles worldwide with, as a result, a quarter of all the petroleum ever consumed in the history of the world consumed in the last 10 years. Australia's total dependency on oil products for all its transport options, the limited and diminishing supply of oil, and the fact that Australia is not self-sufficient and relies on daily imports from politically volatile regions are serious national security issues. Oil consumption also contributes to the problem of greenhouse-gas emissions and, while improving vehicle fuel efficiency can assist, alternative fuel options deserve serious consideration.

The Parliamentary Library's Climate Change web publication provides an overview of alternative fuel types and applications. These fuels include ethanol, biodiesel, compressed and liquefied natural gases (CNG and LNG), propane, biogas, methanol and hydrogen.[8]

Contrary to popular perceptions, the transport sector contributes a relatively small but nevertheless growing portion of overall national greenhouse gas emissions. According to the report *Tracking to the Kyoto Target: Australia's Greenhouse Emissions Trends 1990 to 2008-2012 and 2020*, in 2005 transport accounted for just 14 per cent of the total net $CO_2$-equivalent emissions.[9] The report also notes that from the 1990 base to 2008–12 'Transport emissions (where over half of emissions are from cars) are projected to grow by 42 per cent.'[10] A more detailed analysis of greenhouse gas emission projections, in a paper by the Department of Climate Change states that:

> In 2005, emissions from *Road Transport* (comprising *Cars*, *Light Commercial Vehicles*, *Trucks and Buses* and *Motorcycles*) made up 88 per cent of *Total Transport* emissions, with

6. Australian Automobile Association, U.S. brings in new fuel efficiency standards, media release, 20 May 2009, viewed 8 July 2009, http://www.aaa.asn.au/publications/media_releases.php?action=view&media_releaseId=385

7. ATC, p. 35.

8. Parliamentary Library, *Climate change*, Parliamentary Library, Canberra, 2009, viewed 30 June 2009, http://www.aph.gov.au/library/pubs/ClimateChange/index.htm

9. Department of Climate Change, *Tracking to the Kyoto target: Australia's greenhouse emission trends 1990 to 2008–2012 and 2020*, Department of Climate Change, Canberra, 2008, p. 6, viewed 8 July 2009, http://www.climatechange.gov.au/projections/pubs/tracking2007.pdf

10. Department of Climate Change, p. 5.

> *Cars* – the most important subsector – alone accounting for 54 per cent of *Total Transport* emissions.[11]

The Australian Academy of Technological Sciences and Engineering (ATSE) recently called for a goal of zero transport carbon emissions by 2050 with a Government objective to reduce national dependence on imported hydrocarbon fuels for transportation. It launched a new report *Biofuels for Transport: A Roadmap for Development in Australia* that finds there is no 'silver bullet' or panacea for Australia's oil dependency.[12] ATSE suggests that LNG and CNG commercial vehicle use serve as viable prototypes for wider applications. Further, second generation biodiesel and ethanol (from sugars, not starches) research and use will assist, while in the longer term the applications of hybrid, electric and other vehicles may emerge. The Academy believes that the Australian car industry can develop such vehicles.

The ATSE Biofuels report emphasises second generation biofuels (ethanol from ligno-cellulose wastes, biodiesel from enzyme or algae sources) rather than the first generation which relied heavily on competing food resource stocks. The study finds Australian research and development in biofuels is very good, but limited and requiring linkages both here and overseas. The report recommends that a National Biofuels Institute be established, a larger entity than a Cooperative Research Centre but with links to Bioenergy Australia, the National Collaborative Research Infrastructure Strategy (NCRIS) and so forth. The report says biofuel production investment is needed along with co-production with less developed countries. Australia's wide open areas might suit algae derived fuel production. Alternative fuels only account for some three per cent of total fuel consumption in Australia. According to the ATSE, any change will be incremental and requires ongoing research and development. So the transport sector's contribution to reducing greenhouse gas emissions will be modest.

This Parliamentary Library note therefore focuses on some of the new technical systems that may facilitate new vehicle types. This report does not consider human-powered vehicles, sail craft, etc. The text here focuses on different types of "green" vehicle technology including hybrids, electric cars, compressed air and hydrogen vehicles. It looks at Australia's role and issues of safety regulation, global production realities and evaluating alternatives.

## Pathways to progress

'If you can dream it, you can do it' Walt Disney.

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11. Department of Climate Change, *Transport sector greenhouse gas emissions projections 2007*, Department of Climate Change, Canberra, 2008, p. 3, viewed 8 July 2009, http://www.climatechange.gov.au/projections/pubs/transport2007.pdf

12. Australian Academy of Technological Sciences and Engineering (ATSE), *Bio-fuels for transport: a roadmap for development in Australia*, ATSE, Parkville 2008, viewed 30 June 2009, http://dpl/Books/2008/ATSE_BiofuelsForTransport.pdf

There have been all sorts of attempts to produce vehicles propelled by different fuel sources. In 1886, Karl Benz received the first patent for a gas-fuelled car. Compressed-air engines have been used in some vehicles since the 1800s. In 1901, Ferdinand Porsche unveiled a ‘mixed’, gas-electric hybrid car. Later during World War II, even coal and oil from shale were used to power vehicles.

Various types of electric/battery-powered cars have been made for over a century. The American Baker Motor Vehicle Company sold thousands of its electric cars from 1899 to 1915. They could reach just 23 kilometres per hour (kmph). In 1990, General Motors (GM) introduced its ‘EV’ concept two-seater which had a top speed of 120 kmph, had a range of 120 kilometres, and could accelerate from 0 to 90 kmph in less than seven seconds. Only one thousand were made.

Other types of innovation include fuel cells and hybrid designs. Fuel cells combine fuel (usually hydrogen) and oxygen to produce electricity through chemical reaction**.** GM designed its first fuel-cell car as early as 1966, but it was too expensive to produce commercially. In 1989, Audi produced a plug-in parallel hybrid with an electric motor to drive the rear wheels. By 1998, a Toyota RAV4 sport utility, the Honda EV Plus sedan, and the Chrysler EPIC minivan were all equipped with nickel metal hydride battery packs.

Hybrid vehicles and hydrogen cars are often viewed as a future panacea but the costs and delays along the development path prove to be significant obstacles. Certainly, the use of smaller vehicles and more efficient diesel models can reduce pollution.[13] But with Chinese and Indian citizens now aspiring to personal car use, action is needed to address the limited fuel supplies and the congestion and pollution problems that lie ahead.

Various popular media promote advances in prototype vehicles, such as the BBC television programme *Top Gear* that tested the Tesla electric vehicle and the Honda Clarity hydrogen car, or the recent glossy picture book *Green Designed: Future Cars*.[14,15] Newsagent magazine racks are full of glossies promising new green car types. There are all sorts of new entrants that range from the BMW Mini E and Mitsubishi i-MiEV which plug into normal electric power to recharge their batteries, to the Ford Fusion and Toyota Prius hybrid engine types.[16,17]

13. J Halpert, ‘Diesel vs. hybrid’, *Newsweek*, 4 February 2009, viewed 20 July 2009, http://www.newsweek.com/id/183150

14. U Bethscheider-Kieser, *Green designed: future cars*, avedition GmbH, Stuttgart, 2008, viewed 8 July 2009, http://www2.avedition.de/en/Bucher/Katalog/268

15. ’Volting ambition’, *Top Gear*, British Broadcasting Corporation (BBC), Series 12, episode 7, 2008, viewed 8 July 2009, http://www.topgear.com/uk/tv-show/series-12/episode-7

16. J Voeleker, ‘Top 10 tech cars of 2009: electric-drive cars take second place to sheer survival’, *IEEE Spectrum*, April 2009, pp. 38–47, viewed 8 July 2009, http://www.spectrum.ieee.org/energy/fossil-fuels/top-10-tech-cars-of-2009

## Hybrid vehicles

Hybrid vehicles can combine a conventional engine with a battery-powered electric motor to achieve improved fuel economy and performance. The battery is charged from regenerative braking, which captures as electrical power much of the energy normally lost as frictional heat. Just as a motor can transform electrical energy stored in a battery into motive force, which produces wheel rotation and hauling power, the process can run in reverse with the force created by slowing a moving car regenerating electricity for accumulation in a battery.[18]

Hybrids might be able to save around 30 to 50 per cent of fuel compared to conventional cars. It is estimated that around 20 per cent of the energy used in the burning of fuel actually moves the standard car. Of the 80 per cent lost, about 40 per cent goes down the exhaust and 30 per cent is cooled by the radiator.[19] Hybrids can also use the time when engines are idling to charge their batteries, but the extra weight of batteries and the higher cost serve as barriers.

Hybrid vehicles combine advanced electronics and computerised drive-trains to achieve improved fuel economy and reduced emissions, together with better acceleration and greater range. A hybrid vehicle can get by with a smaller internal-combustion engine than a conventional automobile because the battery and electric-motor system provides additional power when it is needed for acceleration or hill-climbing.[20] This discussion refers to hybrid vehicles, biofuel and flexi-fuel variations.

Hybrids can be classified in various ways.[21] In series hybrids, a petrol engine provides power for the batteries which power the car through an electric motor. In parallel hybrids, an electric motor boost the regular engine's power with the electric motor also run as a generator to reload the battery:

> A 'serial hybrid' uses an internal combustion engine directly to power an electrical motor, which then powers the wheels. Serial hybrids have the advantage of simplicity, but they lose some efficiency by converting mechanical energy from the internal combustion energy into electricity and then back into mechanical energy to power the wheels. A 'parallel hybrid'

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17. 'EVs popping up everywhere', *ReNew*, no. 107, April–June 2009, pp. 40–44.

18. JJ Romm and AA Frank, 'Hybrid vehicles', *Scientific American*, April 2006, vol. 294, no. 4, pp. 56–63.

19. D Adams, 'How tomorrow's cars will leave a lighter footprint', *CSIRO Solve*, June 2008,viewed 8 July 2009, http://www.solve.csiro.au/0608/article1.htm

20. Adams, 2008.

21. Electric Vehicle Association of Asia Pacific, 'What is electric vehicle', viewed 30 June 2009, http://www.evaap.org/what_is_electric_vehicle.html

> works by having both an internal combustion engine and an electric motor connected to the wheels, with either (or both) powering the car at any time.[22]

Plug-in hybrids use large battery packs that can tap into external electricity. Plug-ins that use electricity are expected to reach showrooms in the next few years. In 2005, Toyota made kits available for Prius owners wishing to convert their hybrids into plug-ins.

The extra expense of the large battery and motor and the associated power electronics means that **a hybrid inevitably costs more than a regular car**. The premiums for current hybrids range from an extra US$3 000 to US$7 000 with US$4 000 being an average. The electric-motor and battery pack can add a weight penalty. The new hybrids from Honda and Toyota are around 40 per cent more efficient but cost around 25 per cent more than existing vehicles. The hybrid's fuel saving advantage is mainly in city traffic **whereas on the highway a diesel car may be just as efficient**. The 10 year life of a hybrid's batteries is also an issue if they require replacement as they may cost up to A$6 000. There is also a battery disposal issue.[23]

## Hybrid prototypes

'If shared problems lessen the burden, how come we get so upset in a traffic jam?' PK Shaw.

In the US, more than 40 different hybrids and alternative fuel models, or 8 million cars and light trucks, are already on the roads. By 2006 more than 250 000 drivers had purchased the Toyota hybrid Prius variants on sale there. Toyota has a one million sale target for 2010:[24]

> From 1997 through the first half of 2006, aggregate global hybrid sales for new cars and light trucks totalled 820,000 units. In 2005, 20% of sales took place in Japan, and 68% went to the largest market, the United States. Toyota dominated the aggregate market with more than 720,000 units sold by July 2006, or almost 9 of every 10 hybrids in the world. The demand for the Prius exceeded everybody's expectations, and the hybrid market grew faster than any other.

Toyota's hybrid technology appears to be the most advanced in terms of patents, with 650 on its 'Prius'.[25] The luxury arm of Toyota, Lexus, also offers some hybrid models but these are

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22. T Dean, 'Green limousines', *Cosmos*, no. 11, 2006, pp. 55-63, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/download/library/jrnart/MU2M6/upload_binary/mu2m62.pdf;fileType=application/pdf#search=%22tim%20dean%20cosmos%22

23. E Hannan, 'Hybrid batteries spark waste fears', *The Australian*, 26 August 2008, p. 1, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/download/media/pressclp/SUCR6/upload_binary/sucr60.pdf;fileType=application/pdf#search=%22Ewin%20Hybrid%20Hannan%22

24. N Carr-Ruffino and J Acheson, 'The hybrid phenomenon', *The Futurist*, July–August 2007, pp. 16–22, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22library%2Fjrnart%2FUEWN6%22

more expensive. In March 2006, Lexus announced its 'GS 450h' hybrid sedan, which was followed in September 2006 by the Australian launch of the 'RX 400h 4WD' vehicle. As well as Toyota and Honda, Ford entered the American market with the first hybrid sports utility vehicle; the Escape with 350 patents. GM has offered hybrid trucks and buses and two light hybrid cars; the Chevrolet 'Silverado' and the 'GMC Sierra'.[26] Nonetheless some observers feel that the big three American automakers are far behind.

The prototype of the first ever Hungarian hybrid vehicle called 'Solo' was on display in June 2008 at the Museum of Transport in Budapest, Hungary. The three-seat, 3.12 metre long and 1.92 metre wide vehicle said to be powered by methane gas and lithium-ion batteries was designed and built by the ANTRO Group based in Hungary.[27] The gas-electric vehicle can reach 140 kmph top speed and is expected to go on sale in 2012. The Solo is one half of the still-being-planned Duo which is to be the result of two Solo cars connected together!

Around 4 000 hybrids are sold in Australia each year according to the Federal Chamber of Automotive Industries vehicle sales statistics.[28] The market appears to be rising but it is still a small percentage of vehicles and, more prominent in the private sector presumably due to fleet procurement policies. In May 2008, GM Holden stated that a petrol-electric hybrid Commodore could appear soon in Australia.[29] The Holden ECOmmodore launched in mid 2000 combines a specialised electric motor with advanced lead-acid batteries and a four-cylinder aluminium alloy engine.[30] The vehicle claims to use 50 per cent less fuel than a full-sized family car.[31] GM Holden Australia exports to Brazil a flexi fuel version of the Commodore that runs on high ethanol blends, but it is not available in Australia because of the limited fuel distribution infrastructure here. In Brazil, the majority of cars can run on either pure ethanol or a petrol-ethanol blend called gasohol.

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25. Toyota Motor Corporation, *Hybrid Synergy Drive*, viewed 30 June 2009, http://www.hybridsynergydrive.com

26. Chevrolet, *Chevy Volt: the future is electrifying*, Chevrolet website, viewed 30 June 2009, http://www.chevrolet.com/experience/fuel-solutions/electric/

27. Antro Group website, viewed 8 July 2009, http://www.solo-duo.hu/main.php?lang=en

28. Federal Chamber of Automotive Industries (FCAA), *Vehicle sales*, FCAA website, viewed 30 June 2009, http://www.fcai.com.au/sales

29. J Dowling, 'Holden vows to beat Toyota in local hybrid race', *Drive*, 20 May 2008, viewed 30 June 2009, http://www.drive.com.au/Editorial/ArticleDetail.aspx?ArticleId=52647,

30. Holden, 'ECOmmodore is Australia's first 'green' car', 24 May 2000, viewed 9 July 2009 and *Holden innovation*, GM Holden website, viewed 30 June 2009, http://www.holden.com.au/holden-innovation

31. R Beeby, 'Green car – a coodabeen champion', *Canberra Times*, 11 June 2008, p. 1, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressclp%2FLZOQ6%22

There are also other means of improving the fuel efficiency of existing vehicles. The use of superchargers, to force more air and increase engine power with less fuel; fuel injectors that measure fuel more precisely than carburettors; or variable valve control.[32] GM Holden Australia is studying lightweight materials and alternative fuel efficiency in its quest.

## Flex fuel vehicles

The US Government fuel economy website defines flex fuel vehicles as follows:

> Flexible fuel vehicles (FFVs) are designed to run on gasoline (petrol) or a blend of up to 85% ethanol (E85). Except for a few engine and fuel system modifications, they are identical to gasoline-only models.[33]

For public interest, the US Government maintains a list of the flex fuel vehicles in the US, but there appears to be no comparable list in Australia[34]. GM announced in February 2008 that half of its US vehicle volume will be able to run on ethanol by 2012, increasing its range of flex fuel vehicle models from 11 to 15 by 2009.[35]

The 2006 OECD/International Energy Agency *World Energy Outlook* states:

> In several countries, "flex-fuel" vehicles, which allow consumers to switch freely between high-proportion ethanol blends and gasoline, have recently become available. This insulates the consumer from any sudden jump in the price of ethanol relative to gasoline that might result from a supply shortage or a drop in gasoline prices.[36]

Ethanol is used as a fuel in flex-fuel cars while biodiesel may be another possibility. The flex fuel vehicles do not have any loss in performance compared to petrol when operating on Ethanol at 85 per cent (E85) but they typically get about 20 to 30 per cent fewer kilometres per litre when operating on E85 than with petrol, because of the lower energy content of ethanol.

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32. 'The old motor roars back', *The Economist*, 16 August 2008, pp.73–74, viewed 9 July 2009, http://www5.economist.com/displaystory.cfm?story_id=11919344

33. US Department of Energy, *Flex-Fuel vehicles*, US Department of Energy website, viewed 30 June 2009, http://www.fueleconomy.gov/feg/flextech.shtml

34. US Department of Energy, *Fuel economy guide*, US Department of Energy website, viewed 30 June 2009, http://www.fueleconomy.gov/feg/byfueltype.htm

35. 'GM plans crop of ethanol cars', *Canberra Times*, 8 February 2008, p. 9, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressclp%2FJELP6%22

36. International Energy Agency (IEA), *World energy* outlook, OECD/IEA, Paris 2006, viewed 30 June 2009, http://dpl/Ejournals/OECD_WorldEnergyOutlook/2006.pdf

In Australia, the ‘Ford E-Gas’ vehicle is available in Falcon XT and Futura sedans and wagons. Ford’s E-Gas engine which uses liquefied petroleum gas (LPG) as fuel, is said to be fully integrated with Falcon’s engine management system and instrumentation and can travel further on a full tank of fuel than the petrol equivalents. There is a long history of LPG car conversions in Australia with many different car models running here on the fuel.

Liquefied natural gas (LNG) is used in heavy transport. Wesfarmers Energy Ltd provides LNG fuel for use by heavy duty truck fleets.[37] The Kwinana facility in Western Australia, produces 175 tonnes per day for use by over 100 rigs, while a separate Melbourne gas storage now serves a growing eastern state operation. LNG is highly compatible with diesel, enables fast refuelling and is fleet cost effective, according to its proponents.

Biodiesel, like bioethanol, is derived from the chemical transformation of biological materials. Both biological fuels are now both produced in Australia. There is a range of new European vehicles suited to biodiesel use. The Citroen C-Cactus diesel-electric hybrid or the Citroen C4 BioFlex runs on petrol or bioethanol, or a mixture of both. The ‘Smart For Two’ hybrid diesel two seater has a 33 kilowatt (kW) 0.8 litre diesel engine and a 20 kW electric motor in parallel with a battery recharged by the diesel engine and through regenerative braking. The ‘Peugeot 308 HDi’ diesel-electric hybrid will have an 80 kW 1.6 litre engine coupled with a 16 kW electric motor to provide 96 kW when used in parallel. The hybrid will also run in electric-only mode up to 50 kmph for urban centre usage. The ‘Saab E85’ ethanol is another example of the European car industry moving to meet market expectations.

A third biological fuel is biogas, which is methane with a biological origin. The biogas solution is often overlooked, particularly in its application to developing countries. A short documentary film called *Bate’s Car - Sweet as a Nut* features an inventor called ‘Bates’ and his biogas car which had run for 17 years on methane gas he had produced by processing pig manure.[38] Bates lived in Devon, UK and in the film talks through the simple process and benefits of running a car on biogas. The conversion was simply made with an adapter attached to any combustion engine. Similar claims have come from China and India.

## Plug-in hybrids

A further variation on hybrids are plug-in hybrid electric vehicles (PHEV) which consist of a battery pack recharged through the electricity grid and/or the internal combustion engine (ICE). The ICE may provide for faster acceleration or longer trips. PHEVs are exciting automotive engineers and energy analysts alike:

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37. Wesfarmers Energy , ‘Who is Wesfarmers energy?’, Wesfarmers Energy website, viewed 9 July 2009, http://www.wesfarmersenergy.com.au/

38. National Film Board of Canada, ‘Bate’s car – sweet as a nut’, 1974, NFBC website, viewed 9 July 2009, http://www.onf-nfb.gc.ca/eng/collection/film/?id=11056

> For one thing, say the sceptics, plugging in will be expensive and will stress the already overloaded power grid. Actually, that is unlikely. Because drivers will mostly plug in their cars overnight they will benefit from cheaper off-peak power rates. In America, using cheap electricity to power cars can reduce the cost per mile by *75%* compared with petrol (or even more, given current high petrol prices). The savings are even greater in Europe, which has high petrol taxes. True, if many drivers plugged in during the day it would raise peak demand, but software in the cars could prevent daytime charging.[39]

In Australia, plug-in hybrid electric vehicles are under development by Szencorp and Sydney University of Technology. They use converted Prius cars fitted with extra batteries and power sockets for external charging. The PHEVs can be charged directly from a normal household power point and can travel up to 1 000 km without refuelling. The PHEVs run on electricity for over 30 km at low speeds, the average daily commute of many Australian motorists. For longer trips they revert to normal hybrid operation.[40]

Whether plug-in is necessarily any more greenhouse-friendly depends on the way in which the mains electricity is generated. Such vehicles, with their lower emissions of pollutants, could certainly improve air quality in congested cities. Plug-in power might be used in reverse to sell to the grid for auxiliary power loads. The take-up of PHEV's will increase electricity consumption, but the demand may be met by carbon-neutral sources such as solar, nuclear, wind, hydro-electric and biomass energy. But as most charging would be overnight, little change is required to existing electricity supply infrastructure.[41]

Another type of home recharging is the use of mains household natural gas refuelling of a hybrid vehicle. Honda proposes importing a version of its Civic sedan to run on compressed natural gas (CNG). There are regional variations in natural gas quality around Australia and issues with design standards. However, Californian motorists use the system already.[42]

The Better Place company advocates an electric car unit.[43] Launched in October 2007, Better Place is building electric recharge grids (ERG) in Israel, Denmark, Australia and California.

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39. 'Plugging into the future', *The Economist*, 10 June 2006, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/download/library/jrnart/ZJIM6/upload_binary/zjim63.pdf;fileType=application/pdf#search=%22Plugging%20into%20the%20future%22.

40. Institute for Sustainable Futures, *Szencorp PHEV – Australia's first PHEV*, University of Technology Sydney, Institute for Sustainable Futures, viewed 30 June 2009, http://www.isf.uts.edu.au/whatwedo/szencorpphev.html

41. B Woodall, 'Plug-in autos charged overnight OK for grid', *Reuters*, 30 June 2009, viewed 20 July 2009, http://www.reuters.com/article/GCA-GreenBusiness/idUSTRE55S63G20090630

42. B Park, 'Gas powered, naturally', *The Age*, 6 August 2008, *Drive* p. 3, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/download/media/pressclp/HV6R6/upload_binary/hv6r60.pdf;fileType=application/pdf#search=%22Gas%20powered,%20naturally%22.

43. Better Place, *The solution*, Better Place website, viewed 30 June 2009, http://www.betterplace.com/solution/

Wide scale deployment of electric vehicles is set for Israel, Denmark and Australia (starting in the ACT) in 2011, while California and Hawaii are slated for 2012.[44] The Australian partner is AGL Energy and Macquarie announced in October 2008. According to Kevin Bullis[45]:

> In the plug-in version of the Toyota Prius, the extra battery can be recharged from an electrical outlet. GM has announced that it is developing plug-in hybrids that use advanced lithium-ion batteries and could be ready within a few years. Generating the electricity to power plug-in cars causes less greenhouse-gas pollution than burning gasoline does. There is a giant "if" in all this, though. To become practical and economically viable, plug-in vehicles will need to be mass-produced. And their fate will depend on whether automakers learn from the success of conventional hybrids and fully embrace the new technology… But the mock-up was also a harsh reminder that when it comes to green innovation, U.S. automakers have long been eager to show off flashy concept cars than to manufacture vehicles that work.

## Electric vehicles

In general terms an electric vehicle (EV) uses rechargeable batteries, while other types include electric vehicles that store electricity in electrical or physical devices. There has been a long history of EV developments but little take-up. A 2006 film, *Who Killed the Electric Car,* claimed that car makers and oil firms, as well as apathetic consumers and weak governments had conspired to end California's electric dream, along with various European schemes.[46] The film contends that the Californian Government had mandated that Zero Emission Vehicles comprise up to 10 per cent of the state's fleet by 2003, but its targets were not met and the scheme fell victim to legal action from carmakers. GM decided to sue the Air Resources Board, the Californian regulator that had required the emission-free vehicles. By 2004 all EVs were off the road, repossessed by GM.

The saga of the Reva Electric car in Australia is also illustrative.[47] The Indian-built Reva is a fully automatic (no clutch, no gears), two-door hatchback, seating two adults and two children. A small turning radius of just 3.5 metres makes it easy to park and manoeuvre in difficult city traffic conditions. It runs on batteries and, unlike other electric vehicles, it has an onboard charger to facilitate easy charging which can be carried out by plugging into any

44. V Violante, 'Electric car plan: ACT set to plug in', *Canberra Times*, 25 July 2009, p. 1, viewed 27 July 2009, http://www.canberratimes.com.au/news/local/news/general/electric-car-plan-act-set-to-plug-in/1577774.aspx

45. K Bullis, 'Electric cars 2.0', *Technology Review*, September–October 2007, vol. 110, no. 5, pp. 100–101.

46. Sony Pictures Classics, *Who killed the electric car*, Sony Pictures Classics website, viewed 30 June 2009, http://www.sonyclassics.com/whokilledtheelectriccar

47. Reva Australia, *REVA technical specifications: why EVs*, Reva Australia website, viewed 30 June 2009, http://www.revaaustralia.com.au/revaabout.htm

15 amp socket at home or work. A full battery charge takes less than seven hours and gives a range of 80 km. In quick-charge mode (two and a half hours) 80 per cent charge is attained, good enough for 65 km.

Reva was extensively tested and certified by the Automotive Research Association of India (ARAI) and received the European Economic Community (EEC) certificate in December 2003, paving the way for an aggressive move into European markets. The certification marked the commercial entry of Reva into the UK with an order for 500 cars. However, the vehicle had great difficulty passing the Australian Design Rule process and remains unavailable in this country. In 2007, Reva entered 13 countries and is in the process of expanding capacity by over five times to over 30 000 units. Company officials say 80 per cent of the company's cars are sold in 21 markets abroad including the UK and Japan where there is more awareness about the environment and electric cars are more acceptable.

Meanwhile, in early 2009, President Obama called for a million electric vehicles to be on the road by 2015, by making available A$3.5 billion for the industry development of new electric cars. Further comment on electric vehicles can be found on the Australian Electric Vehicle Association website.[48]

## Electric dreams

The market and image of hybrids continues to grow and improve. In Britain, the campaign for electric vehicles increases.[49] According to *The Engineer* magazine:

> Although electric cars are increasingly popular with environmentally-conscious urban commuters, their low speeds, boxy shapes and long charge times have done little to make the Jeremy Clarkson's of the world ditch their 'milk float' gags and dash down to the showroom. This could be about to change however, thanks to a number of projects, at varying stages of development, that promise a new generation of battery-powered cars with Ferrari-style performance. Also, in a gratifying thumbs-up for UK automotive engineering expertise, three of the most significant of these projects draw heavily on home-grown talent.
>
> The closest to production is the US-developed Tesla Roadster, a US$98,000 all-electric sports car that goes from 0-60 in four seconds, travels more than 200 miles between charges, and boasts a waiting list that reads like a Who's Who of Hollywood high society. But although the Tesla is by far and away the closest high- performance electric car to production, it could soon be followed by a UK pretender.
>
> Announced in a blaze of publicity several months ago, the Lightning GT is a UK-developed electric sports car that could go into production next year. Key to the success of all-electric vehicles are the battery packs, and Lightning's engineers have embraced an interesting

48. Australian Electric Vehicle Association, *AEVA FAQs*, viewed 30 June 2009, http://www.aeva.asn.au/faq.htm

49. Battery Electric Vehicles, 'Campaign for battery electric vehicles', Battery Electric Vehicles website, viewed 30 June 2009, http://www.cbev.org/

> solution. Rather than lithium-ion batteries, the Lightning will use a series of batteries called NanoSafe, derived from a research project launched by the US firm Altairnano in 2000.[50]

The Tesla is said to reach up to 200kmph and only require 3.5 hours recharge time with its lithium-ion batteries. By mid 2008, some 900 Teslas had been reserved. They are noted for their very quick acceleration of 0 to 100 kmph in up to 5 seconds and their sporty design. In March 2009, Tesla unveiled a new electric 5-seat sedan to become available by 2011. With a lithium-ion battery pack it is to have a range of 360 km per charge.

The Microcar ZENN reaches 55 kmph with a range of 55 km and takes nine hours to recharge its six lead-acid batteries used to power the electric motor. ZENN (Zero Emission No Noise) Motor Company has used advanced design techniques to devise its new car, with 250 sold by mid 2008.[51][52] They feature regenerative braking and fast cycle time battery recharging. They cost around US$16 000 and have been sold in the US since 2007. The Dynasty 'IT' sedan also sold in North America since 2001, has lead acid or gel batteries and can achieve 38 kmph with a range of 48 km, requiring 11.5 hours to recharge.

As of early 2009, the only commercially available full electric vehicle in Australia is the Electron, a converted Hyundai Getz with a lithium-ion battery pack. However, industry proponents suggest there are small business opportunities in Australia to convert existing cars into electric vehicles for around A$10 000.[53]

From Asia, Mitsubishi has a test vehicle using lithium batteries and in-wheel motors and will sell its iMiEV electric vehicle from 2009. The parent company of Subaru, Fuji Heavy Industries is working in conjunction with the Tokyo Electric Power Co to develop a Subaru electric vehicle. Nissan has also announced plans to sell an electric car in the US and Japan by 2010.[54] Designed by Italdesign and built in Hong Kong by NICE Car Company, the MyCar electric vehicle is on sale in London for around A$19 000.[55] It has a range of around 64 km and a top speed of 64 kmph and is exempt from road tax and the London congestion charge.

Providing an academic, technically based view of the world, MIT Media Lab's Smart Cities Project advances a radical scheme to provide rentable, stackable, light electric vehicles for

50. 'Electric Cars on the grid', *The Engineer*, 13 August 2007, p. 20.
51. Zenn Motor Company website, viewed 9 July 2009, http://www.zenncars.com/
52. T Hein, 'She is electric, can I be electric too?', *Engineering World*, June–July 2008, pp. 26–31.
53. D Rowe, ''Low-cost' electric vehicles', *ReNew*, no. 107, April–June 2009, pp. 64–68.
54. N Tabakoff, 'Brave new wheels', *Bulletin*, vol. 124, no. 6539, 26 September 2006, pp. 28–34.
55. evstores, 'The electric car of the year is here!', evstores website, viewed 9 July 2009, http://www.evstores.co.uk/my_car.html

inner urban demand.[56] Shared bicycle schemes in cities such as Paris appear to have been very successful showing the way to such a new concept of service provision, rather than reliance on traditional vehicle car industry outputs. Solar/wind roof panels or hydrogen systems might refuel the modular 'City Cars' but requires a mindset change towards urban public transport.

Lithium-ion batteries offer some promise, but until now had high temperature requirement and flammability issues, although recent advances in electrode chemistry and nanotechnology applications may make them safe at ambient temperatures. A new vehicle using this technology is on offer by Norwegian company Think.[57] By 2009, Think hopes to sell its ultra-compact electric car with a range of 180 kms and speed up to 100 kmph. It uses lithium-ion batteries provided by A123 Systems, an American new start-up company, based on specialised electrode materials using nanotechnology.[58][59] It should be able to provide up to fifteen years of daily charging cycles of around four hours each.

Much of the current electric vehicle impetus appears to be centred on the United States. The GM Chevy Volt anticipated in 2012 will also use A123's lithium-ion batteries along with an on-board fuel-powered generator. The Volt may achieve 70 km of commuter driving per charge, with a small ICE engine to recharge the battery and extend its range to 700 km. Californian based Aptera Motors plans to sell both electric and hybrid vehicles in late 2008.[60] Also Californian based, but associated with production of Chinese vehicles, Miles Electric Vehicles has a mission to rapidly develop advanced all electric vehicles. The Miles Electric Vehicles XS500 is capable of 135 kmph using lithium-ion batteries, with an estimated price around A$30 000 from 2009.[61] The US company EV Innovations and its fully owned subsidiary Hybrid Electric Vehicles India offers a range of vehicles.[62] In early 2008, Dodge announced an electric concept car called the Dodge Zeo.[63] There are many other ventures,

56. MIT Media Lab, 'Smart cities', MIT Media Lab website, viewed 9 July 2009, http://www.media.mit.edu/research/groups/smart-cities

57. Think, 'A new city', TH!NK website, viewed 30 June 2009, http://www.think.no

58. K Bullis, 'An electrifying startup', *Technology Review*, May–June 2008, pp. 68–71, viewed 30 June 2009, http://parlinfo.aph.gov.au/parlInfo/download/library/jrnart/1GPR6/upload_binary/1gpr60.pdf;fileType=application/pdf

59. A123 Systems website, viewed 9 July 2009, http://www.a123systems.com/

60. Aptera website, viewed 30 June 2009, http://www.aptera.com

61. Miles Electric Vehicles website, viewed 30 June 2009, http://www.milesev.com

62. EV Innovations Inc., *EVII*, EV Innovations website, viewed 30 June 2009, http://www.hybridtechnologies.com/products

63. 'Electric Dodge ZEO's 250-Mile Range, Sub-Six-Second 0-60 Time May Make Best Concept of 2008: Detroit Auto Show Preview', *Popular Mechanics*, 14 January 2008, viewed 9 July 2009, http://www.popularmechanics.com/blogs/automotive_news/4244408.html

including the newly formed American National Alliance for Advanced Transportation Battery Cell Manufacture for the development and production of lithium-ion batteries, but only time will tell as to which technologies and designs may prevail in the car market.[64]

## Solar and compressed air vehicles

### Solar cars

Perhaps the ultimate form of alternative energy propulsion would be to harness the power of the sun to propel vehicles. Directly solar-powered cars use photovoltaic cells to convert the received sun's energy into electrical energy, which is stored in batteries. Although not yet practical for general use, particularly from a safety aspect as they are more like prone bicycles than cars, their solar technology may help power future hybrid vehicles. The problem with direct solar energy is storing it in sufficient quantity on board to ensure that the vehicle can continue at night or in cloudy weather.

Australia has been a testing ground for many designs of solar cars. The World Solar Challenge, which began in 1987, has seen the world's best sunlight-driven vehicles travel down the Stuart Highway from Darwin to Adelaide.[65] The GM Sunraycer won the first event with an average speed of 67 kmph while the 2005 winner was the Nuna3, built by students from the Netherlands Delft University of Technology, with a good average speed of 103 kmph. In 2007, the Nuna 4 from Delft won in 33 hours at an average speed of 90.87 kmph. The Australian HybridAuto venture aims to develop an all-electric two seat car capable of 200 km at up to 170 kmph based on a model that completed the 2008 World Solar Challenge.[66]

Of interest is the trial by the Adelaide City Council of the Tindo solar-powered electric bus.. The bus is manufactured by the New Zealand company, Designline International, and has a regenerative braking system, saving up to 30 per cent energy consumption, and uses a solar photovoltaic recharging system at the bus station. It uses 11 Zebra batteries and can carry 42 passengers up to 200 kilometres.

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64. A Stern, 'U.S. government lab, 14 firms team up on lithium battery', *Reuters*, 19 December 2008, viewed 9 July 2009, http://planetark.org/wen/50975 and Argonne National Laboratory, *Transportation Technology R&D Centre*, viewed 30 June 2009, http://www.transportation.anl.gov/

65. World Solar Challenge website, viewed 9 July 2009, http://www.wsc.org.au/welcome.html

66. P Heininger, 'Plugged in and switched on to the fast lane', *Australian Financial Review*, 20 August 2008, p.6, viewed 9 July 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressclp%2FXCER6%22

## Compressed air cars

Compressed air vehicles use the expansion of compressed air to drive their pistons instead of mixing fuel with air and burning it in the engine to drive pistons with hot expanding gases. They are powered by an air engine, which uses compressed air that is kept stored in a tank onboard. The main thing to note is that the compressed air must initially be provided using some form of energy. The tanks may be refilled at a suitably equipped service station or in a few hours at home or at a parking area, plugging the car into the electric grid via an on-board compressor.

Cars could run entirely on compressed air for urban driving but another possibility is a hybrid using both petrol and compressed air. One of the disadvantages of compressed air is that it has a lower energy density than batteries or the same weight of petrol, but in urban driving situations compressed air is useful as it can readily store the energy given off when vehicles brake. Such a pneumatic hybrid could run on petrol but utilise the stored compressed air energy when required. By using the engine itself with the pistons pumping air into storage when braking, the stored air could help improve combustion for acceleration, rather akin to a turbocharger.[67]

The concept is not new and is said to offer a number of advantages including centralisation of power supply, reduced vehicle manufacture and maintenance costs, low pollution and simplicity. Proponents claims that compressed air requires less change to current infrastructure than other alternate sources. However, these gains may be offset by less inbuilt safety robustness and problems arising in low temperatures. Obviously the existing interests of the car industry, oil suppliers and government taxation policies may not necessarily favour any initial production of compressed air vehicles.

The French 'CAT' (compressed air technology) prototype engine operates on four cycles: intake and compression, combustion, expansion and exhaust. Outside air is drawn into the combustion chamber and compressed which heats it to 400 degrees and then receives an injection from the storage tank. As the injected air is much colder than compressed air in the chamber, the former is heated rapidly to cause a sudden expansion stroke of the piston and then exhaust. The vehicle may have an electronically controlled continuously variable transmission.

Motor Development International of Nice, France has proposed a range of vehicles developed on an identical CAT concept.[68] The MiniCAT is a small vehicle with three-abreast seating with a range of 170 km and a recharging time of four hours. Several CitiCAT variants are

67. 'Running on air', *The Economist: Technology Quarterly*, 6 June 2009, p. 5, viewed 10 July 2009, http://www.economist.com/sciencetechnology/tq/displayStory.cfm?story_id=13725715

68. Motor Development International website, viewed 30 June 2009, http://www.mdi.lu/english/index.php

envisaged: a taxi (five seats), a pick-up (two seats) and a van (two seats) with a stated urban range of 240 km.[69] MultiCAT is a project of a modular vehicle for the transport of passengers or carriage of goods. OneCAT is a plan for an economical car (€3 500) less than 500 kg. It is proposed to be sold in India to Tata Motors and in Europe. MDI plans to also design a petrol station compressor which would fill the tanks in three minutes.

Tata Motors is a multinational corporation headquartered in India and is India's largest passenger car and commercial vehicle manufacturing company.[70] After acquiring Land Rover and Jaguar and announcing plans to enter the European market Tata plans to release a MiniCAT compressed air car with a lightweight fibreglass body built on a glued tubular chassis. Reports say around 6 000 cars are planned to appear on Indian streets by August 2009. Costing around A$8 000 each, they may have a rural range up to 300 km.

Tata announced in March 2009 the commercial production of its A$3 000 'NANO' car, a 30 horsepower, four-speed, up to five seat car with a 0.6 litre petrol engine that is claimed to offer low fuel consumption. This 'People's Car' was launched at the New Delhi Auto Expo in early 2008 aiming to suit the Indian family car market.[71]

A working compressed air cart vehicle used by staff at the Queen Victoria Market in Melbourne was developed by Engineair Research & Development.[72] Based in Melbourne the company focuses on developing air motor technology based on a rotary piston concept. Said to be different from conventional air motors, the Engineair motor, invented by Mr Angelo Di Pietro, claims to virtually eliminate internal wear and friction and offer superior performance for a wide variety of applications:

> The Di Pietro motor concept is based on a rotary piston. Different from existing rotary engines, the Di Pietro motor uses a simple cylindrical rotary piston (shaft driver) which rolls, with low friction, inside the cylindrical stator. The space between stator and rotor is divided in 6 expansion chambers by pivoting dividers. These dividers follow the motion of the shaft driver as it rolls around the stator wall. The motor shown is effectively a 6 cylinder expansion motor.
>
> The cylindrical shaft driver, forced by the air pressure on its outer wall, moves eccentrically, thereby driving the motor shaft by means of two rolling elements mounted on bearings on the shaft. The rolling motion of the shaft driver inside the stator is cushioned by a thin air film. Timing and duration of the air inlet and exhaust is governed by a slotted timer which is mounted on the output shaft and rotates with the same speed as the motor.

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69. 'MDI MiniCat & CitiCat air cars', Greencar.com website, viewed 10 July 2009, http://www.greencar.com/articles/mdi-minicat-citicat-air-cars.php
70. Tata Motors website, viewed 30 June 2009, http://www.tatamotors.com/
71. Tata Motors, 'Nano', Tata Motors website, viewed 10 July 2009, http://tatanano.inservices.tatamotors.com/tatamotors/
72. Engineair Pty Ltd, *Engineair R&D*, viewed 30 June 2009, http://www.engineair.com.au/

There are a number of other inventors, companies and claims for compressed air vehicles.

Deakin University designed a model that runs on compressed air as part of its participation in the Ford Global Challenge to design a Model T for the 21st Century. Deakin University was the only Australian university invited to participate in the Challenge, part of the 2008 celebrations for the 100th anniversary of the Model T Ford, the car that changed the 20th Century. On 1 October 2008 Ford announced that this car along with one from Germany was a winner. ‘The entry from Deakin was described by Ford as: “pushing the boundaries and delivering an alternative transportation concept for tomorrow.”’ The new model T design aims to be universally affordable and will retail for under US$7 000.[73]

Cars running entirely on compressed air are emission-free at the 'tailpipe', but the energy, usually electric, required to recharge the compressed air tanks may cause emissions elsewhere, depending on how the method used for the generation of mains electricity. As with rechargeable battery vehicles, compressed air cars therefore may still cause net emissions of greenhouse gases and other air pollutants, perhaps not as much as from onboard fossil fuel use, with emissions relocated from streets to where the power generators reside. However, the slight upside is that an air motor releases air that is cleaner than its intake, due to the presence of an air filter to keep contaminants out of the mechanism. Consequently, this can be viewed as air purification instead of air pollution! The bottom line is that credible compressed air car production is yet to start anywhere in the world, despite deals and developments. As with electric vehicles or hydrogen types they face an up-hill battle in the global car market.

## Hydrogen vehicles

According to the United Kingdom Parliamentary Office of Science and Technology in a 2002 publication on *Prospects for a Hydrogen Economy*:

> For transport, hydrogen can be burned in an internal combustion engine (ICE), in the same way as petrol or natural gas. BMW currently uses this technology to power a fleet of demonstration vehicles. This produces water as the main by-product, but also small amounts of oxides of nitrogen, an air pollutant. Dual fuel ICE vehicles have been produced to run on both hydrogen and petrol. Hydrogen can also be used to power fuel cell vehicles.
>
> Using hydrogen in fuel cells is more efficient than combustion, with efficiencies of up to 45%, compared with up to 25% for a dual fuel ICE. Therefore a fuel cell car could travel

73. Deakin University, *T2 proves a winner in Global Challenge*, media release, October 2008, viewed 15 July 2009, http://www.gsdm.com.au/newsletters/deakin/Oct08/t2.html

> over twice as far as a dual fuel ICE car on the same amount of hydrogen. Hydrogen ICE and fuel cell cars are currently at the demonstration stage.[74]

## Prototype hydrogen cars

After 1990, vehicle developments took on various directions with some manufacturers choosing to explore fuel cell technologies, while others investigated hydrogen ($H_2$) combustion engines. Today, around 50 $H_2$ vehicle models exist from 26 manufacturers. Although most of these are concept cars or prototypes, some are designed for limited production. Mass production is not yet a commercial reality. The models can all be classed into one of two engine categories:

- fuel cell vehicle (FCV) that combines hydrogen with oxygen from the air in a chemical reaction, producing electricity.
- hydrogen-fuelled internal combustion engine ($H_2$ICE) vehicles that combust hydrogen and oxygen to produce energy and water.

Of all the $H_2$ vehicle prototypes, around 40 run on fuel cell technology. The most common $H_2$ fuel cell is the Polymer Electrolyte Membrane (PEM) fuel cell. A PEM fuel cell uses oxygen and pressurised hydrogen to create electricity, outputting heat and steam as by-products. The FCV runs on 'stacks' of these fuel cells in order to continuously generate enough electricity for a special motor and power converter to produce around 100 kW. The primary advantage of the FCV over the $H_2$ICE vehicle is in the reduction of moving parts, resulting in reduced maintenance requirements. However, $H_2$ does require special handling and storage for safety.

The $H_2$ICE vehicle was originally considered the 'transition' vehicle to assist in the move to a dominant FCV-market. This is because the motors are essentially the same as traditional petrol-powered internal combustion engines, with total manufacture costing only about 15 per cent more..[75] The main differences with a conventional ICE engine are increased compression ratios and the requirement for a supercharger (booster) to achieve adequate power output. Some manufacturers, such as Mazda and BMW, have been able to develop 'dual fuel' engines. $H_2$ICE vehicles can be designed to run on either liquid or gaseous hydrogen, the choice of which will have an effect on tank requirements. A liquid $H_2$ tank requires significant insulation, while a gaseous $H_2$ tank must cater for high pressures.

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74. Parliamentary Office of Science and Technology (POST), 'Prospects for a Hydrogen Economy', *postnote*, no. 186, October 2002, viewed 30 June 2009, http://www.parliament.uk/post/pn186.pdf

75. US Department of Energy (DOE), *Retooling today's engines for the hydrogen economy*, Energy Efficiency and Renewable Energy, Vehicle Technologies Program, DOE website, February 2008, viewed 15 July 2009, http://www1.eere.energy.gov/vehiclesandfuels/features/fcvt_feature_retooling_engines.html.

The 1996 Mercedes-Benz DaimlerChrysler NECAR 2 fuel cell vehicle had a top speed of 100 kmph with a range of 240 km. Today's Mercedez-Benz hydrogen powered fuel cell A-class F-cell car is said to be the first using $H_2$ fuel cell power rather than $H_2$ as an ICE fuel. Icelandic energy companies are using the new car for a year's tests. Iceland produces hydrogen using geothermal energy or hydro power. The F-cell has a range of 160 km and works by means of fuel cell electricity driving the car up to speeds of 140 kmph.[76]

Today's Honda FCX Clarity has a range of 450 km and can travel at 160 kmph.[77] The first were delivered in July 2008 to customers in California, part of the first fuel cell vehicle dealership network. The latest Clarity has a 25 per cent increase in combined fuel economy and a greater than 30 per cent increase in driving range. The electric motor runs on electricity generated in the fuel cell, and the only emission is water. Fuel efficiency is three times that of a modern gasoline-powered automobile.

The BMW concept sedan 7 series is powered by a V12-cylinder internal combustion engine, liquid hydrogen fuel or petrol and achieves 191 kW, with a top speed electronically limited to 230 kmph. This $H_2$ICE vehicle has a range of 240 km on hydrogen with the associated infrastructure requirements. The BMW Hydrogen 7 is not yet available for sale to the general public, but is available to VIPs to promote and demonstrate its functionality.[78] BMW experts in clean energy urge governments around the world to encourage alternative powered vehicles such as hydrogen fuel.[79]

The US Chevrolet Hydrogen Equinox is powered by a 93 kW fuel cell, 73 kW front-wheel drive, an electric motor and a 35 kW nickel metal hydride battery pack. It features three pressurized carbon fibre fuel tanks, with a range of 380 km and a top speed of 160 kmph. Chevrolet has launched its three-year 'Project Driveway' in which several hundred residents of New York, Washington, DC and Southern California are provided a total of 60 Equinoxes for a number of weeks, months or even years to test for day-to-day use.[80] It should be noted

76. J McCall, 'Hydrogen cars come in many colours, but they're all green', *Sydney Morning Herald*, 26 July 2007, p. 6, viewed 15 July 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressclp%2FMESN6%22

77. FCX Clarity, Honda website, viewed 15 July 2009, http://automobiles.honda.com/fcx-clarity/

78. 'BMW Hydrogen 7', BMW website, viewed 15 July 2009, http://www.bmw.com/com/en/insights/technology/efficient_dynamics/phase_2/clean_energy/bmw_hydrogen_7.html

79. N McDonald, 'Hydrogen help plea', *Herald Sun*, 1 February 2008, p. 7, viewed 15 July 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressclp%2FM9JP6%22.

80. Chevrolet, 'Fuel cell', Chevrolet website, viewed 30 June 2009, http://www.chevrolet.com/experience/fuel-solutions/fuel-cell/

that California has more than 26 hydrogen fuelling stations. The website [Fuelcells.org](http://www.fuelcells.org) contains a chart of fuelling stations worldwide.[81]

An average medium-sized petrol car today can travel between 500 and 600 km on a tank, and although top speeds are usually above 200 kph, speed limits in Australia never exceed 120 kph. So, in 20 years, technology has put $H_2$ cars almost on par with petrol cars, but fuel cell developments have had problems with cost, storage and refuelling problems.

The Western Australia Department of Transport conducted a trial in Perth, of three hydrogen fuel cell buses, known as EcoBuses from September 2004 to September 2007. This was the first significant use of hydrogen as a transport fuel on public roads in Australia. At the conclusion of the trial EcoBuses had travelled approximately 258 000km, consumed over 46 tonnes of hydrogen and carried over 320 000 passengers.[82]

## Hydrogen economy

The UK Parliamentary Office of Science and Technology notes that

> there are still issues of cost, reliability and lifetime, such that fuel cell cars are not expected to reach mass markets until after 2015. As there is considerable experience with ICEs, some consider that they may be important in the interim.[83]

The US National Academies in a report on hydrogen released 16 July 2008 says that:

> The maximum practical number of HFCVs that could be operating in 2020 would be approximately 2 million in a fleet of 280 million light-duty vehicles. The number of HFCVs could grow rapidly thereafter to about 25 million by 2030. … The substantial financial commitments and technical progress made in recent years by the automotive industry, private entrepreneurs, and the U.S. Department of Energy (DOE) suggest that HFCVs and hydrogen production technologies could be ready for commercialization in the 2015-2020 time frame. Such vehicles are not likely to be cost-competitive until after 2020, but by 2050 HFCVs could account for more than 80 percent of new vehicles entering the fleet.[84]

While there has been publicity given to a future 'hydrogen economy' in which all fuels would be seemingly replaced by manufactured hydrogen, the need for cost reduction, effective demonstration and infrastructure development mean that mass markets are unlikely in the

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81. 'Worldwide hydrogen fueling stations', fuelcells.org website, viewed 15 July 2009, http://www.fuelcells.org/info/charts/h2fuelingstations.pdf

82. 'EcoBus - Perth fuel cell bus trial', Department of Transport website, viewed 15 July 2009, http://www.dpi.wa.gov.au/greentransport/19524.asp

83. POST, 'Prospects for a hydrogen economy', p.2

84. National Research Council of the National Academies, *Transitions to alternative transportation technologies—a focus on hydrogen*, National Academies Press, Washington, DC, 2008, viewed 15 July 2009, http://books.nap.edu/openbook.php?record_id=12222

near future. A key feature is how the hydrogen is obtained. It is possible to generate it from water, but this is generally more expensive than obtaining it from methane. Either way, energy is required to carry out the chemical reaction—the fundamental question is the origin of this energy. A hydrogen economy is not necessarily all 'green' unless the energy used to obtain the hydrogen is environmentally friendly in origin.

Another aspect is the handling characteristics of hydrogen as a fuel. For fuel use it may have to be in the liquid state, which can be more bulky than the equivalent carbon-based fuel, and require extensive insulation.[85] An aspect of hydrogen fuel cell utilisation is the application of platinum catalytic converters—units that improve fuel cell reactions. (Platinum is sourced from relatively few sites around the world.)[86] New research into cheaper polymer catalysts may help.[87] There are reports too of shortages of the rare earth element dysprosium that is used in advanced electric motors and battery systems.

Doubting the viability and feasibility of establishing a hydrogen economy, in May 2009 the new Obama administration sought to cut back research into automotive hydrogen fuel cells, but this move was overturned by the US Congress.[88] The administration believed that biofuels and plugin hybrids might offer better short-term transitions to more efficient motoring. Meanwhile, California continued to promote its hydrogen road tour and trials.[89]

## Australian automobile developments

### Research and development (R&D)

Here, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has been investigating the conversion of methane natural gas into hydrogen and oxygen through the

85. GA Olah, A Goeppert, GKS Prakash, *Beyond oil and gas: the methanol economy*, Wiley-VCH, Weinheim, Germany, 2006, pp. 145–149, viewed 15 July 2009, http://books.google.com.au/books?id=xH_JyuL08K4C&printsec=frontcover&dq=Beyond+Oil+and+Gas:+The+Methanol.

86. Olah, p. 163.

87. C Graber, 'Hydrogen power on the cheap--or at least, cheaper', *Scientific American*, 31 July 2008, viewed 30 June 2009, http://www.sciam.com/article.cfm?id=hydrogen-power-on-the-cheap&sc=WR_20080805

88. J Tollefson, 'US Congress revives hydrogen vehicle research', *Nature*, vol. 460, 23 July 2009, pp. 442–443, viewed 27 July 2009, http://www.nature.com/news/2009/090721/full/460442b.html

89. R F Service, 'Hydrogen cars: fad or the future?', *Science*, vol. 324, no. 5932, 5 June 2009, pp. 1257–1259.

use of a catalytic conversion involving solar energy at its National Solar Energy Centre.[90] A test plan is running at a solar research facility in Newcastle with a pilot in Queensland.

CSIRO is active in vehicle R&D in Australia with research that aims to develop electric drive train systems, energy storage systems (such as super-capacitors and battery technologies) and power control systems. In the medium term, Australia will have to plan for a decline in local oil supplies and a future transport fuels scenario will be part of CSIRO's modelling program.

The CSIRO Energy Transformed Flagship (ETF) technology development in this area builds on developments in hybrid electric and fuel cell powered cars and successful development of the earlier ECOmmodore hybrid and the aXcessAustralia Mark II proof-of-concept vehicle.[91] The ETF advanced research into the UltraBattery combines a super-capacitor with a lead-acid battery in a single unit to create a long-lasting hybrid battery. The UltaBattery is now being built by Japanese company Furukawa.[92]

There are many other CSIRO auto-related activities:

- involvement in light metal application to improve fuel economy, such as the T-Mag permanent-mould casting process for magnesium, rather than traditional aluminium.
- research into the use of the lost engine heat to generate electricity using a thermo-electric heat effect to pump heat from one side of a vehicle to another. This can also link to the vehicle's climate-control system.
- researching bio-fuels, synthetic fuels, direct use of gases (CNG, LNG, LPG, hydrogen) including production, usage costs, and infrastructure requirements.

There are other local activities of note. The Cooperative Research Centre for Advanced Automobile Technology (AutoCRC) is looking at techniques and processes to strengthen the viability of the Australian automobile industry.[93] The 2007 AutoCRC Duoleta concept car

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90. National Solar Energy Centre', CSIRO website, viewed 15 July 2009, http://www.det.csiro.au/science/r_h/nsec.htm

91. Commonwealth Scientific And Industrial Research Organisation (CSIRO), 'Flagship research into low emissions transport', CSIRO website, viewed 30 June 2009, http://www.csiro.au/science/LowEmissionsTransportResearchOverview.html; 'Holden unveils "green" car', Autoweb 24 May 2000, viewed 30 June 2009, http://autoweb.com.au/cms/A_52517/newsarticle.html; CSIRO, 'aXcessaustralia: a concept car for the not-so-distant future', CSIRO website, viewed 30 June 2009, http://www.csiro.au/solutions/aXessaustralia.html; Axcess Australia, viewed 30 June 2009, http://www.herelectricvehicle.com/axcess.html

92. 'Ultrabattery: no ordinary battery', CSIRO website, viewed 15 July 2009, http://www.csiro.au/science/Ultra-Battery.html

93. AutoCRC website, viewed 30 June 2009, http://www.autocrc.com

incorporates ultra low fuel consumption technology with a low kerb weight and yet achieves respectable road performance.

## Car industry policy

On 10 June 2008, Prime Minister Kevin Rudd announced a $35 million deal with the giant Japanese vehicle maker Toyota to build hybrid cars in Australia. With the funding directed to R&D support, Toyota will build hybrid Camrys at its Melbourne factory. A $500 million 'Green Car Innovation Fund' has been set up to promote the development and production of low-emission and fuel-efficient vehicle technologies in Australia. This will be an effective $500 million subsidy to the Australian car industry to produce 'hybrid and low-emission vehicles', despite some industry scepticism.[94] Indeed, some industry observers claim that we had a hybrid capability a decade ago, with the ECOmmodore, but lost that advantage.[95]

On 15 August 2008, Senator Kim Carr, Minister for Innovation, Industry, Science and Research released the ('Bracks') report of the Review of Australia's Automotive Industry.[96] He said that 'A range of new technologies is being developed to meet demand for low-emission, fuel-efficient vehicles, but no-one can say which technologies will succeed'. The report recommended bringing forward to 2009 and doubling the Green Car Innovation Fund to $1.3 billion. On 11 November 2008, Senator Carr and Prime Minister Kevin Rudd announced 'A New Car Plan for a Greener Future' with a $6.2 billion, 13 year long commitment to provide Australian car companies with an opportunity to receive funding to design and sell environmentally friendly cars.[97] The Innovation Fund will see the Australian Government match industry investment in green cars on a one dollar to three dollar basis over a ten year period from 2009, along with a number of other associated measures.

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94. G George, 'Can we still make cars in the green economy?', *Australian Options Magazine*, Autumn 2008, pp. 19–21.

95. Beeby, 'Green car – a coodabeen champion'.

96. K Carr (Minister for Innovation, Industry, Science and Research), *Brack's report maps auto future*, media release, 15 August 2008, viewed 15 July 2009, http://minister.innovation.gov.au/Carr/Pages/BRACKS'REPORTMAPSAUTOFUTURE.aspx and http://www.innovation.gov.au/automotivereview/Pages/ReviewofAustralia'sAutomotiveIndustry.aspx

97. K Carr (Minister for Innovation, Industry, Science and Research) and K Rudd (Prime Minister), *A new car plan for a greener future*, media release, 10 November 2008, viewed 15 July 2009, http://minister.innovation.gov.au/Carr/Pages/ANEWCARPLANFORAGREENERFUTURE.aspx

## Safety issues

The Federal Government has refused Australian Design Rules (ADRs) approval for various small cars such as the proposed Reva two-seater city electric runabout, on the basis of safety concerns regarding such 'quadricycles'.[98] The Government claims that Reva's importer failed to undertake mandatory crash testing requirements within a new vehicle category. It is known from crash analysis (e.g. Used Car Safety Ratings) that vehicles which barely meet these standards have three or four times the fatality risk of the better performing vehicles. Any vehicles which failed to meet the minimum safety standards could be expected to have a higher risk. Australia follows international standards.

In essence, all motorised road vehicles must meet the ADRs that set out national design standards for vehicle safety and emissions. The ADRs do not have specific requirements for electric vehicles but do set minimum safety standards, mostly for body strength, brakes and lights. Importation requirements are controlled in part by the Federal Department of Infrastructure, Transport & Regional Development and Local Government (DITRDLG). Decisions about vehicle registration requirements are made by the Australian Motor Vehicle Certification Board which comprises Federal and State representatives and is managed by DITRDLG. The Board introduced a national code of practice for light vehicle construction and modification that 'outlines the minimum design, construction, installation and performance requirements for modifications to light vehicles'. In this code a light vehicle is defined as having 'Gross Vehicle Mass of 4.5 tonnes or less'.[99]

Generally speaking, smaller alternative vehicle types would appear to be unsafe in terms of the likely injury caused to their occupants in the event of collision with larger cars and commercial vehicles. Many electric vehicle designs seem to be of a smaller vehicle type and so may have safety concerns. On the other hand, the manufacturer of the so-called 'Smart Car' series, Mercedes-Benz claims that it incorporates many safety features to make up for its small size.[100] Nonetheless, the laws of physics will determine the outcome, in the event of

98. Department of Infrastructure, Transport, Regional Development and Local Government (DITRDLG), Australian Design Rules, 3rd edition, DITRDLG, Canberra, viewed 30 June 2009, http://www.infrastructure.gov.au/roads/motor/design/adr_online.aspx

99. 'National code of practice for light vehicle construction and modification: introduction', *Vehicle Standards Bulletin 14*, February 2006, viewed 15 July 2009, http://www.infrastructure.gov.au/roads/vehicle_regulation/bulletin/pdf/NCOP2_Intro_3Feb2006.pdf

100. J Dowling, 'Smart car for the open-minded', *Sydney Morning Herald*, 6 June 2008, p. 14, viewed 15 July 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressclp%2FL5PQ6%22

such a small vehicle crashing into a large truck. That said, Smart Cars offer very efficient motoring even if they use conventional petrol engines.[101]

Electric cars have been successfully designed and manufactured to meet these minimum standards. In April 2009, the Mitsubishi MiEV plug-in electric car, that met all the applicable ADRs; was certified by the Australian Government for use on our roads. The MiEV's 47 kW motor has a bank of lithium ion batteries which can be charged from a household 240 V power supply in little more than seven hours. Built in Japan, the four-seater, rear-wheel drive MiEV is speed limited to a top speed of 130kmph and has a range of up to 160 kilometres.[102]

As a side issue, but one worthy of note, associations of blind people have expressed concern about hybrid and electric vehicles being hazardous because they make very little noise to alert people of their presence. There are currently trials being undertaken by Lotus in conjunction with the Guide Dogs for the Blind Association to fit vehicles with simulators that make a noise the same as a petrol engine.[103] In the US Congress there is presently a bill to establish a minimum sound level for vehicles not using petrol engines. The EU is looking to do the same.‘[104]

## Futurama

In New York, at the 1939–40 World’s Fair and again at the 1964–65 World’s Fair, GM presented Americans with ‘Futurama’, the corporation’s vision of the future city and its vehicles; visions which largely came to pass.[105] With its profits currently in steep decline, GM may again need to reassure US citizens with its view of future motoring, be it a green or sustainable vision. GM has also played a major role in the Australian car industry so its future here is of interest, particularly amid the current global financial crisis.

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101. ‘Smart car’ website, viewed 15 July 2009, http://www.smart.com/

102 A Albanese (Minister for Infrastructure, Transport, Regional Development and Local Government), *Australia leads the world; all electric car gets the thumbs up*, , media release, 08 April 2009, viewed 30 June 2009, http://www.minister.infrastructure.gov.au/aa/releases/2009/April/AA116_2009.htm

103. U Khan, “Electric cars to sound like noisy sports cars to protect the blind and cyclists’, *Telegraph.co.uk*, 10 May 2009, viewed 24 July 2009, http://www.telegraph.co.uk/motoring/5303600/Electric-cars-to-sound-like-noisy-sports-cars-to-protect-the-blind-and-cyclists.html

104 ‘The sound of silence: electric cars and noise’, *The Economist*, 9 May 2009, p. 73 and ‘The sound of silence’, *Economist.com*, 7 May 2009, viewed 24 July 2009, http://www.economist.com/displayStory.cfm?story_id=13606446.

105 R Volti, *Cars and culture: the life story of a technology*, Johns Hopkins University Press, Baltimore, MD., 2004, viewed 15 July 2009, http://books.google.com.au/books?id=mmcbJ2tSzNMC&printsec=frontcover&dq=Cars+and+Culture:+The+Life+Story+of+a+Culture

Former Senator Lyn Allison wrote in 2008 that Australia lagged behind other countries in not requiring the vehicle industry, by regulation of conditional handouts, to be responsive to alternative energy demands, through subsidising low emission car production and refuelling.[106] By contrast in New Zealand, former Prime Minister Helen Clark, announced in October 2007, as part of an 'Energy Strategy to 2050', that the country would aim to have 5 per cent of cars as 'plug-ins' by 2020 and 60 per cent by 2040 along with 25 per cent to have fuel cells by 2050.[107][108]

Automobile manufacturers conceive their designs to appeal to the vanity and paying capabilities of their customers, with traditionally a strong emphasis on personal image and performance motoring. The realities of daily commuting congestion, spiralling fuel costs, accidents and pollution have only been addressed by manufacturers in more recent times. Consider, for example, the slow implementation of 'Electronic Stability Control' into commonly available models here, with claims that the Australian market is being denied such safety features unless we regulate for them. The Labor Government announced in July 2008 that Australia was joining an international push for consistent, world-wide technical standards for 'Electronic Stability Control'.[109][110]

Therefore to claim that the introduction of hybrid models is deliberately slow ignores the realities that automobile makers will only create new models when they sense true market demand and one willing to pay for the usually very large implementation costs of changing to new technologies. Of course some manufacturers receive government subsidies or other forms of support, but these do not necessarily ensure desired outcomes as the recent demise of Mitsubishi in Adelaide illustrates. Governments can distort markets by providing incentives/disincentives to encourage movement towards alternatives. Also some externalities are not included in the typical calculation of the cost of a conventional vehicle but are instead absorbed by society.

106. L Allison, 'Australia: an auto backwater', *Online Opinion*, 14 February 2008, viewed 15 July 2009, http://www.sciencealert.com.au/opinions/20081502-16905-2.html

107. George, 'Can we still make cars in the green economy'.

108. Ministry of Economic Development (MED), 'New Zealand energy strategy', MED website, viewed 15 July 2009, http://www.med.govt.nz/templates/ContentTopicSummary____19431.aspx

109. A Albanese (Minister for Infrastructure, Transport, Regional Development and Local Government), *Australia signs up to new global car safety regulation*, media release, 22 July 2008, viewed 15 July 2009, http://www.anthonyalbanese.com.au/file.php?file=/news/QKTPHQWZFYWUAKVPXYPPESYY/index.html

110. Note that 'electronic stability control' is 'an active safety system that reduces the risk of a driver losing control of the vehicle' and' builds upon features such as anti-lock braking systems (ABS) and traction control to stabilise the vehicle when it changes direction from that intended by the driver', Vicroads website, viewed 15 July 2009, http://www.vicroads.vic.gov.au/Home/Cars/RoadSafety/Electronic+Stability+Control.htm.

China is a burgeoning car market and the recent documentary *The Cars That Ate China* is a sobering reflection on the resulting congestion and pollution that will arise if even a small proportion of the Chinese population achieves their aspiration to purchase a car.[111] Foreign corporations have established a number of large vehicle manufacturing facilities in the country and the prospect of Australians driving cars imported from China, as well as India, is not far away.[112] If Australia could involve Chinese interests with developing more fuel efficient or alternative fuel vehicles then we all might at least travel better on the road ahead.

Overall though, it appears that electric or hybrid vehicles are yet to prove themselves as a complete answer. As well, **technical barriers such as the cost of batteries or fuel cell technology** still need an order of magnitude improvement, as does their disposal. The energy used to manufacture the car along with its added complexity **means that the greenhouse gases used to make it may outweigh** any eventual travel savings.[113] (To this end, the appendix examines the use of Life Cycle Analysis to estimate overall savings). **Electricity or hybrid cars may have minimal greenhouse savings unless power comes from green power sources**. All these aspects require careful measurement and further study, suggesting that a combination of responses may offer the best hope for the future.

Some motoring experts suggest that the best thing consumers can do for the moment is to downsize their vehicle to suit their lifestyle or even change to low emission diesel to save around 20 per cent on fuel use compared to a typical petrol engine. Driving smoothly, avoiding warming up, reducing air conditioner usage and lightening loads can also assist.[114] The 2008 CSIRO Fuel for Thought study identified fuel source diversity, suggesting early uptake of EVs over PHEVs. The report articulated a range of scenarios for the future of transport fuels in Australia.

For now, small to medium vehicle fleets can consider use of ethanol, gases and bio-fuels, while large vehicles can utilise LNG, CNG, etc. Delegates to the 2008 ATSE fuels Symposium concluded that there needs to be a coordinating organisation for alternative transport fuels in Australia and a framework for our vehicle fleet to meet current overseas standards. We may also note that there is no Australian Standard or ADR requirement for fuel efficiency in the vehicular fleet, unlike in Europe for example.

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111. D Biello, 'The price of gas in China', *Scientific American*, 4 August 2008, viewed 30 June 2009, http://www.sciam.com/article.cfm?id=the-price-of-gas-in-china&sc=IDR_china

112. Volti, *Cars and culture*, p.148.

113. S Nathan, 'Car plant', *The Engineer*, 26 July–17 August 2008, pp. 20–21.

114. C Sheedy, 'Green revolutions', *Open Road*, September–October 2007, pp. 10–14, viewed 16 July 2009, http://www.openroad.com.au/green_revolutions.asp

Table 1 provides a comparison of models mentioned in this text along with their reported characteristics. Perhaps one thing to say is that there are no real surprises at this stage of model development.

## Table 1 : Comparison of alternative vehicle characteristics

| Technology (Type) | Model (Make) | Range (km) | Top Speed (kmph) | Price (A$) | Efficiency (km/litre) |
|---|---|---|---|---|---|
| **Petrol/diesel** | Holden Barina | 400+ | 100+ | 10 000+ | 13.6 |
| | Holden Commodore | 400+ | 100+ | 30 000+ | 8.5 |
| **Hybrid** | Toyota Prius | 400+ | 100+ | 38 000+ | 19.6 |
| | Honda Civic Hybrid | 400+ | 100+ | 33 000 | 17.9 |
| **Electric** | Tesla | 300 | 200 | 110 000 | 108.9 |
| | Microcar ZENN | 55 | 55 | 18 500 | na |
| | Chevrolet Volt | 70–700 | 100 | 40 000 | na |
| | HybridAuto | 200 | 170 | 100 000 | na |
| **Compressed air** | Indian MiniCAT | 300 | 110 | 6 000 | na |
| **Hydrogen** | Honda FCX Clarity | 450 | 160 | 700/month | 30.6 |
| | BMW concept series 7 | 240 | 230 | 100 000+ | na |

Source: Parliamentary Library estimates and also A Danigelis, '10 of the most fuel-efficient cars in the United States', Discovery Channel: Discovery tech 10 website, viewed 30 June 2009, http://dsc.discovery.com/technology/tech-10/cars-fuel-efficient-top-10-02.html

The development of green cars is facing big hurdles and according to an article by Joseph Romm:

> Alternative fuel vehicles (AFVs) and their fuels face two central problems. First, they typically suffer from several marketplace disadvantages compared to conventional vehicles running on conventional fuels. Hence, they inevitably require government incentives or mandates to succeed. Second, they typically do not provide cost-effective solutions to major energy and environmental problems, which undermine the policy case for having the government intervene in the marketplace to support them…

> There have historically been six major barriers to AFV success:
>
> 1. high first cost for vehicle;
> 2. on-board fuel storage issues (i.e. limited range);
> 3. safety and liability concerns;
> 4. high fuelling cost (compared to gasoline);
> 5. limited fuel stations: chicken and egg problem; and
> 6. improvements in the competition (better, cleaner gasoline vehicles)….
>
> In particular, it is unlikely that hydrogen vehicles will achieve significant (> 5%) market penetration by 2030. A variety of major technology breakthroughs and government incentives will be required for them to achieve significant commercial success by the middle of this century. Continued R&D in hydrogen and transportation fuel cell technologies remains important because of their potential to provide a zero-carbon transportation fuel in the second half of the century. But neither government policy nor business investment should be based on the assumption that these technologies will have a significant impact in the near- or medium- term….
>
> Hydrogen fuel cell vehicles face major challenges to overcome each and every one of the barriers discussed earlier. It is possible we may never see a durable, affordable fuel cell vehicle with an efficiency, range, and annual fuel bill that matches even the best *current* hybrid vehicle. Of all AFVs and alternative fuels, fuel cell vehicles running on hydrogen are probably the least likely to be a cost-effective solution to global warming, which is why the other pathways deserve at least equal policy attention and funding. One AFV, however, has clear environmental benefits, including substantially lower greenhouse gas emissions, a much lower annual fuel bill, a much longer range than current cars (with the added ability to fuel at home), and far fewer infrastructure issues than traditional AFVs. This AFV is the plug-in hybrid also called the e-hybrid. A straightforward improvement to the current generation of hybrids can allow thein to be plugged into the electric grid and run in an all-electric mode for a limited range between recharging. Since most vehicle use is for relatively short trips, such as commuting, followed by an extended period of time during which the vehicle is not being driven and could be charged, even relatively modest all-electric range of 20 to 40 miles could allow these vehicles to replace a substantial portion of gasoline consumption and tailpipe emissions. If the electricity were from CO2-free sources, then these vehicles would also have dramatically reduced net greenhouse gas emissions. [115]

To conclude, there is wide interest in alternative vehicle options such as hybrids, electric vehicles, hydrogen fuel cells and other more radical ideas in the light of rising fuel prices and concern about transport's contribution to climate change and to poor urban air quality. However, the final production of green vehicles available for consumers to purchase and operate will depend on the vagaries of global markets and the ability of the car industry to reinvent itself in a new manufacturing era. Australia's role in that redevelopment presents both challenges and opportunities.

115. J Romm, 'The car and the fuel of the future', *Energy Policy*, vol. 34, no. 17, November 2006, pp. 2609–2614, viewed 16 July 2009, http://climateprogress.org/wp-content/uploads/2009/06/futurecarfuel.pdf

## Addendum

On 2 July 2009, the Council of Australian Governments (COAG) considered the Australian Transport Council/Environment Protection and Heritage Council's March 2009 report on vehicle fuel efficiency measures. This is designed to move Australia towards international best practice. COAG agreed to a range of actions, which include undertaking a 'Regulatory Impact Statement' to assess the costs and benefits of introducing $CO_2$ emission standards for light vehicles. The actions agreed by COAG are set out in the National Strategy on Energy Efficiency.[116]

116. Council of Australian Governments, *National Strategy on Energy Efficiency*, July 2009, viewed 20 July 2009, http://www.coag.gov.au/coag_meeting_outcomes/2009-07-02/docs/Energy_efficiency_measures_table.pdf

# Appendix: Car operation life cycle analysis

On average, only about ten per cent of energy usage in the life of a car is attributable to the vehicle's manufacture, so efforts to save energy or reduce emissions should focus more on improvements to vehicle operation and efficiency. In a Society of Automotive Engineers paper it says ' that:

> In 1998 the United States Automotive Materials Partnership published the life cycle inventory of a generic US family sedan. Several years later, researchers at the University of Michigan expanded this analysis to consider the dynamic replacement decisions over the vehicle lifetime that would optimize energy and emissions performance of generic family sedan ownership. The present study provides further analysis of this vehicle by examining the life cycle cost profile for generic sedan ownership and determining the optimal replacement intervals for this vehicle based on economics.
>
> Life cycle cost for a generic vehicle was estimated as $0.37/mile for a ten-year life cycle and $0.31/mile for a twenty-year life cycle. This study found that while less than 10% of the generic vehicle life cycle energy (20 year) is consumed during material production and manufacturing, 43% of the total life cycle cost is associated with vehicle purchase and depreciation. Nevertheless, both energy and cost factors favour minimizing the number of vehicle replacements in a given time period. Over the 36-year period examined in this study (1985- 2020), the ownership pattern that minimizes total life cycle energy use is replacement every 18 years. While the pattern for minimum life cycle cost is replacement of the first vehicle after 17 years followed by replacement of a second vehicle after 19 years. Further analysis suggested replacement every 9 years could potentially balance a range of cost and environmental objectives.[117]

A report by CSIRO to the former Australian Greenhouse Office, states:

> On a full-fuel cycle basis, when vehicles are normalized to remove mass differences, the lowest greenhouse gas (GHG) emissions are from hybrid electric vehicles. Diesel vehicles emit less exbodied GHG (exbodied emissions are the sum of the pre-combustion emissions and the tailpipe emissions) than petrol, LPG or CNG vehicles, which also means that a diesel-hybrid would have lower exbodied GHG emissions than a petrol-hybrid. Diesel vehicles also have lower exbodied emissions of carbon monoxide and non-methanic volatile organic compounds (NMVOC) than petrol, LPG, and CNG. However, diesel vehicles emit more particulate matter than any other fuel class…
>
> Present day health concerns associated with motor vehicle emissions are predominantly focused on particulate matter (PM10, PM2.5, PM1). LPG (third generation) vehicles have the lowest tailpipe emissions of PM10, but on a life-cycle basis the PM10 emissions from

117. DV Spitzley, DE Grande, Hyung Chul Kim and GA Keoleian, 'Life cycle economics and replacement optimization for a generic U.S. family sedan', Society of Automotive Engineers, April 2005, viewed 30 June 2009, http://www.sae.org/technical/papers/2005-01-1553

LPG and CNG are comparable, and are less than those from diesel, petrol or even hybrid vehicles.[118]

Various tabular comparisons of vehicle types and evaluations are provided in the paper however, overall comparison of different vehicle types may need a wider analysis technique:

> "Well-to-wheel" analysis is the leading holistic approach in measuring the impact of fuel and vehicle choices. A conventional car uses only about one barrel of oil [well) of every 100 extracted from the earth to move its driver down the road (wheel). Since only about 15% of any fuel power ends up turning wheels, efficiency analysis is very insightful.
>
> Well-to-wheel measures everything from fuel extraction to the turning of the wheels. In a conventional vehicle, value chain activities might include oil extraction, pipeline or truck delivery to a port, tanker delivery to another port, truck transportation to a refinery, gasoline delivery to a station, and finally the burning of gasoline to provide propulsion. [119]

A 2007 study used Life Cycle Analysis (LCA) to conduct an environmental assessment of different battery technologies for electric and hybrid vehicles. While battery, hybrid and fuel cell electric vehicles are considered as being environmentally friendly, the batteries they use are sometimes said to be environmentally unfriendly.[120] The LCA concluded that three electric vehicle battery technologies have a comparable environmental impact: lead-acid, nickel-cadmium and nickel-metal hydride, while lithium-ion and sodium-nickel chloride have lower environmental impacts than the three previously cited technologies, when used in a typical battery electric vehicle application. A 2006 study found that when excluding the energy losses during the use phase (due to the battery efficiencies and the additional masses of the batteries), the following ranking is obtained (in decreasing environmental impact): lead-acid, nickel-cadmium, lithium-ion, nickel-metal hydride, and sodium-nickel chloride.[121]

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118. T Beer, T Grant, H Watson & D Olaru, *Life-Cycle emissions analysis of fuels for light vehicles*, CSIRO, Melbourne, 2004, viewed 30 June 2009, http://www.environment.gov.au/settlements/transport/publications/lightvehicles.html

119. Carr-Ruffino and Acheson, 'The hybrid phenomenon', p. 19.

120. J Matheys, W Van Autenboer, J M Timmermans, J Van Mierlo, P Van den Bossche and G Maggetto, 'Influence of functional unit on the life cycle assessment of traction batteries', *The International Journal of Life Cycle Assessment*, vol. 12, no. 3, May 2007, pp. 191-196, viewed 16 July 2009, http://www.springerlink.com/content/t254153m760137w2/

121. P Van den Bossche, F Vergels, J Van Mierlo, J Matheys and W Van Autenboer, 'SUBAT: an assessment of the sustainability battery technology', *Journal of Power Sources*, vol. 162, no. 2, 22 November 2006, pp. 913-919, viewed 16 July 2009, http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TH1-4GXVG7C-3&_user=4962121&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000065915&_version=1&_urlVersion=0&_userid=4962121&md5=aa406693d7049125a08ed62f134cc36a

A 2009 paper compares the lifecycle costs of electric cars to petroleum powered vehicles finding the former to be cost competitive for cars of lower range and with high petrol prices.[122]



122. M Werber, M Fischer, P V Schwartz, 'Batteries: Lower cost than gasoline?', *Energy Policy* 37(2009), pp. 2465–2468, viewed 20 July 2009, http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22library%2Fjrnart%2FR5TT6%22