Supplementary written evidence to the

‘Inquiry into mandatory ethanol and biofuel targets in Victoria’,

Economic Development and Infrastructure Committee, Parliament of Victoria

by

Dr. Michael Brear, Department of Mechanical Engineering, University of Melbourne,

Mr. Anthony Kitchener, SVW Pty Ltd

27th August, 2007

Outline

- Summary of our evidence
- What is on the road?
- Summary of world trends in carbon dioxide (CO_2) emissions regulation
- Summary of world trends in ethanol production
- On-road CO_2 emissions of cars and trucks fuelled by natural gas (CNG and LNG)
- Embedded CO_2 emissions of cars and trucks fuelled by ethanol blends
- Discussion of a potential route for expanding alternative fuel use

Summary of our evidence

Our evidence is specifically concerned with the use of natural gas and ethanol in road transportation. In summary, our views are

- Carbon pricing is not expected to drive the uptake of low GHG fuels in road transportation. Thus, some form of mandate is required in order to reduce GHG emissions from road vehicles.

- Australian jurisdictions are very likely to, and should, follow others in mandating strict GHG emissions per kilometre for road vehicles. This should trigger increased uptake of alternative fuels.

- Vehicles fuelled by natural gas and ethanol blends can have superior GHG and other emissions compared to gasoline, and there is substantial opportunity for further GHG reduction if the engine is fully optimised.

Summary of our evidence, cont.

- A scenario for expanding alternative fuel use:

1. Tighter CO2 emission regulations should force CNG/LNG/LPG engine technologies to become equal to those in contemporary conventional engines, rather than lagging as most after-market conversions presently do (because of the 'cost of conversion'). This is desirable, and should mean that these fuels will complete on a GHG basis with diesel and lower concentration ethanol blends.
2. Mandate that all new single fuel, *gasoline* cars sold be E85 compatible, flex fuel vehicles.
3. Mandate change over to higher ethanol blends in much the same way as the transition from leaded to unleaded petrol; e.g. different pump nozzles.
4. Gradually increase the ethanol content in the new blend in keeping with increased domestic production and imports up to some optimal level.

- In order to consider such a route, substantial further analysis of the likely GHG benefits is required. For example,

1. Care must be taken to avoid *increasing* GHG emissions by creating incentives (e.g. differential fuel pricing) that may encourage vehicle changeover that is too rapid. The appropriate rate of transition for minimum GHG emissions requires detailed study, which to our knowledge has not been performed.
2. If mandated ethanol blending is taken into account when calculating CO_2 emissions / km, more precise energy ratios for all ethanol and gasoline/diesel production routes are essential e.g. [11]
3. Cellolosic ethanol production offers large GHG benefits over other forms of ethanol, as well as more widespread economic benefits across Australia. R&D into this technology is currently being strongly supported around the world, and needs substantially more support locally.

What is on the road?

- Vehicles on the road [2]:

	2002	2006	Change	Average annual growth
	no.	no.	%	%
Passenger vehicles	10 101 441	11 188 880	10.8	2.6
Campervans	35 164	41 520	18.1	4.2
Light commercial vehicles	1 819 993	2 114 333	16.2	3.8
Rigid trucks	341 483	383 546	12.3	2.9
Articulated trucks	63 905	71 680	12.2	2.9
Non-freight carrying trucks	18 797	20 293	8.0	1.9
Buses	70 196	75 375	7.4	1.8
Motor cycles	370 982	463 057	24.8	5.7
Total motor vehicles	**12 821 961**	**14 358 684**	**12.0**	**2.9**

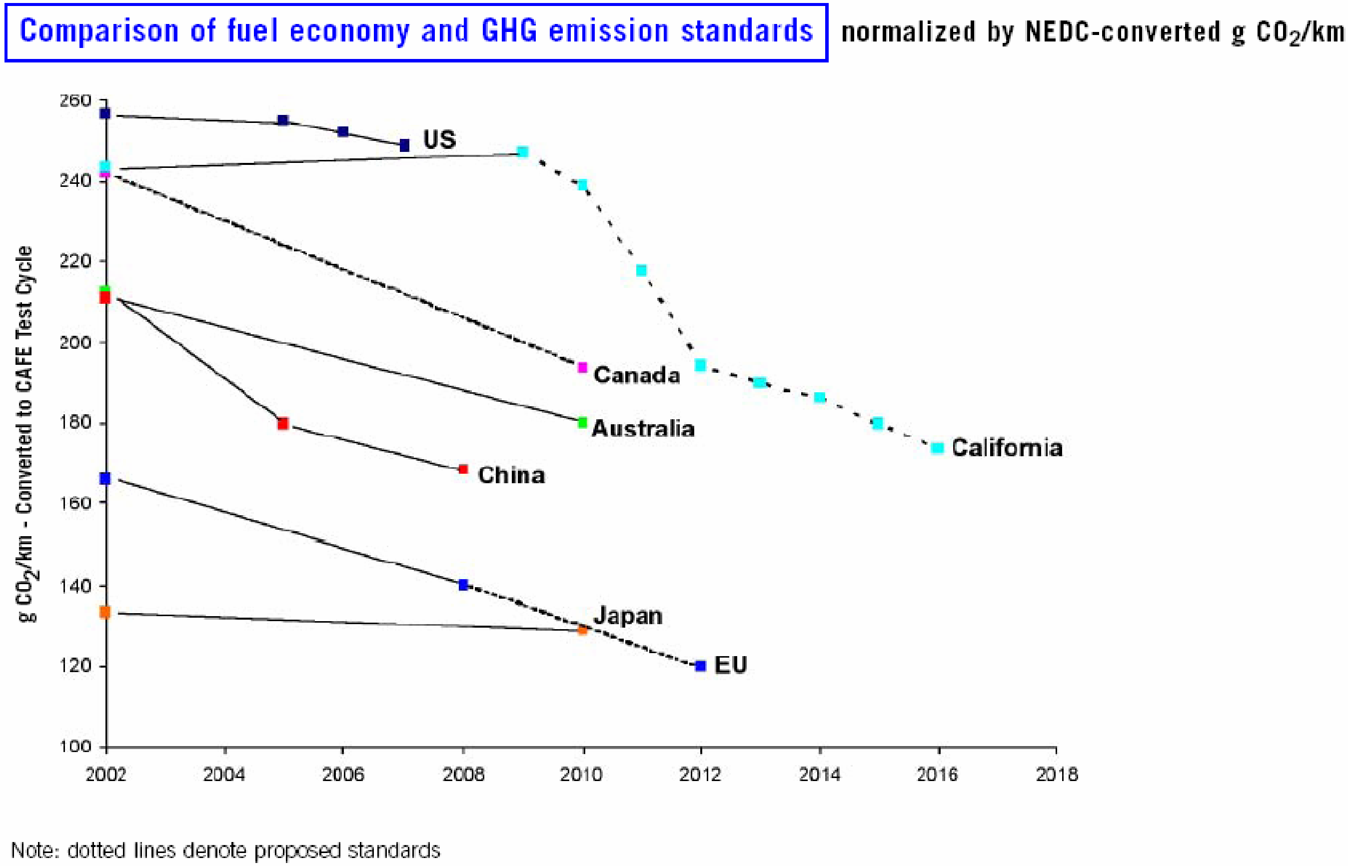
- and their GHG emissions [5]:

TABLE ES.1 EMISSION PROJECTIONS FOR ENERGY END-USE BY AUSTRALIAN DOMESTIC CIVIL TRANSPORT, BTRE 2005 BASE CASE

(Gigagrams of direct CO_2 equivalent)

Year	Cars	Road freight vehicles	Air	Rail	Coastal Shipping	Other	Total	Per cent change from 1990
1990	34214	17493	2564	1741	1868	1902	59783	..
2004	45556	26006	5581	2016	1545	2136	82841	+38.6%

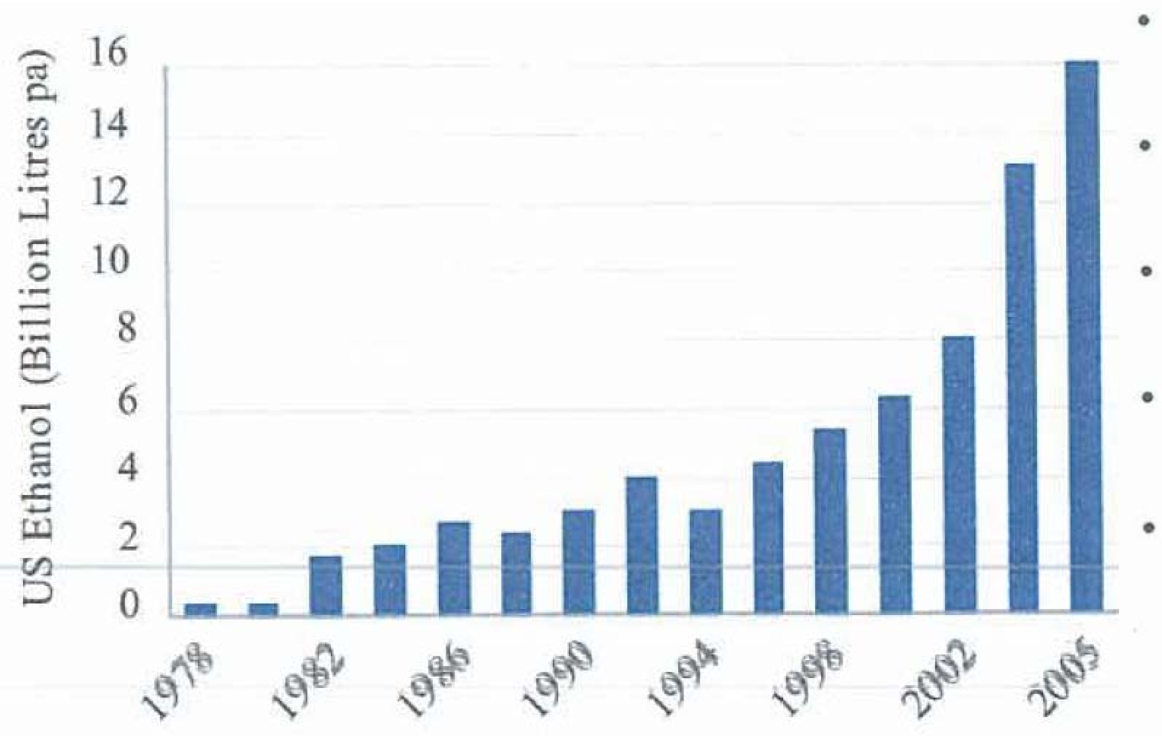
World trends in CO2 emissions regulation [1]



- Note current proposals for mandated CO2 emissions in EU and California.
- Australia, like the rest of the world, traditionally follows.

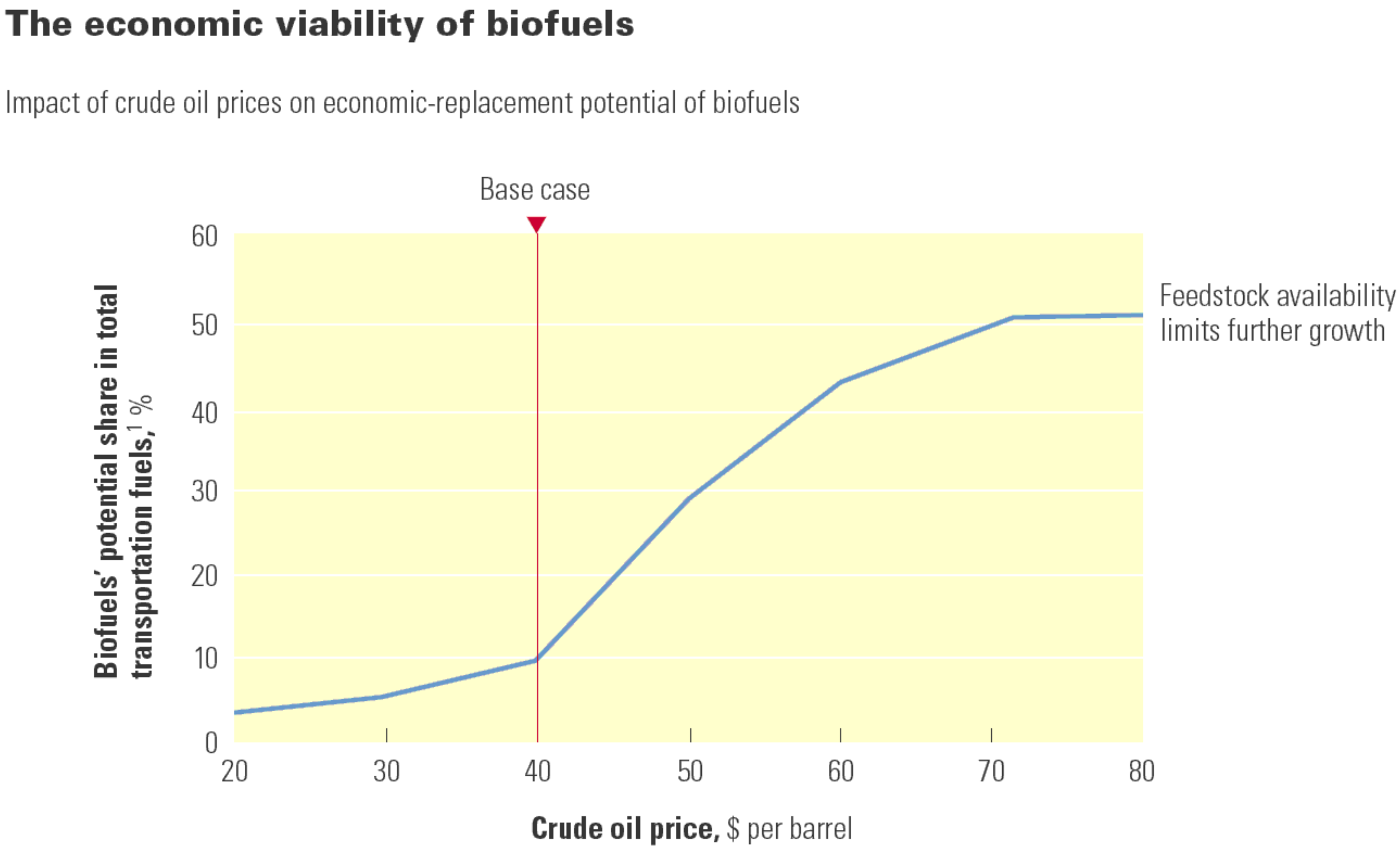
World trends in ethanol production [10]

US ethanol production



- Brazil: 16.5 billion litres pa ethanol from molasses, sugarcane juice and cassava
- US: 16 billion litres pa ethanol from corn (20% total crop) – 2.6% total US liquid fuels
- China: currently 2 billion litres pa ethanol (very large scale future plants projected)
- EU: European Commission set targets by 2010 of 12 billion litres pa (6% total liquid fuel)
- Australia: currently 120–150 million litres (ML) pa; with a target of 350 ML pa by 2010 including biodiesel (approximately 1% of total liquid fuels).

McKinsey study of potential uptake [6]



- At current crude oil prices? Several other studies suggest real economic benefits for Australia e.g. [7,10].

CNG/LNG vehicles

- Compressed natural gas (CNG) passenger vehicles and trucks have been shown to give significant GHG emissions reductions relative to gasoline vehicles, of order 20-30%, which is similar to diesel vehicles [8,13,14]. This is due to 2 effects:

- NG is has mainly methane, which has an inherently lower CO2 emissions per joule of energy produced.
- NG has a significantly higher octane number, allowing higher compression ratio and therefore higher efficiency.

- Also, emissions of other pollutants, in particular particulates, are significantly better than for gasoline and diesel fuels

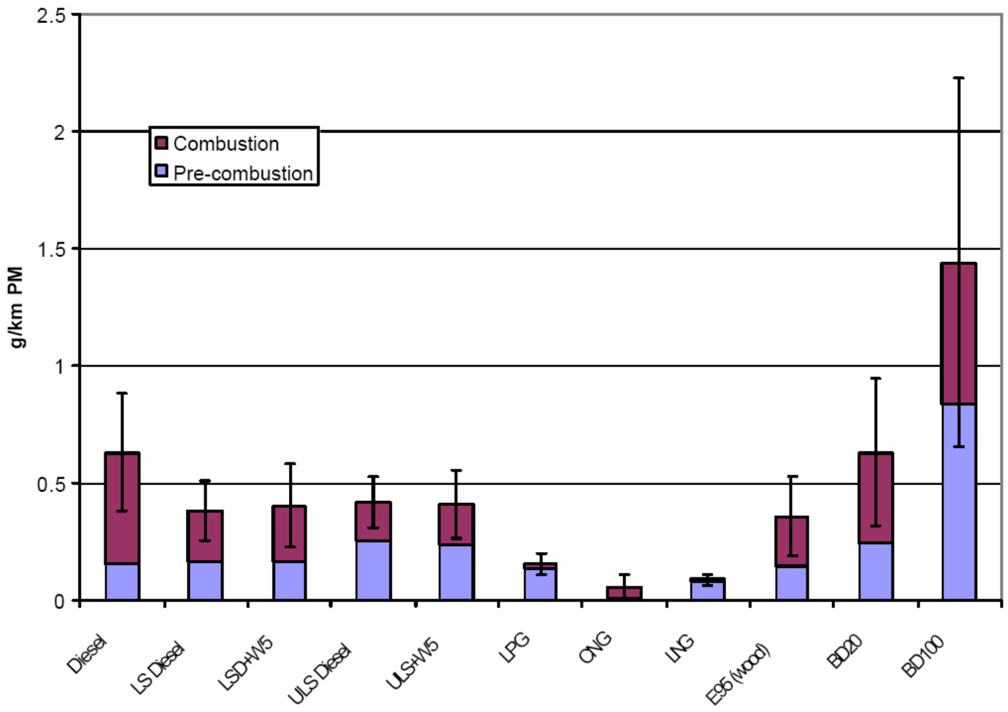


Figure 3

Particulate matter emissions (g/km) for urban buses

From [4]

CNG/LNG vehicles, cont.

- However,

1. the composition of natural gas varies across the nation, making engine optimisation and reliability a challenge.

2. Current engine technologies, like that of LPG vehicles, are usually not optimised to obtain minimum fuel consumption and thus minimum CO_2 emissions. Rather, these engines are usually built by converting existing gasoline or diesel engines, where the cost of conversion is a significant consideration.

3. CNG vehicles are usually range limited because gaseous fuels are not dense enough, and they do not have a developed supply infrastructure. As a result, uptake has strongly featured vehicles with fixed routes or bases e.g. buses, taxis, etc and not passenger vehicles in particular.

4. Liquefied natural gas (LNG) vehicles overcomes these problems in range, but at the expense of greater cost of implementation and higher embodied CO_2 emissions in the liquefaction process.

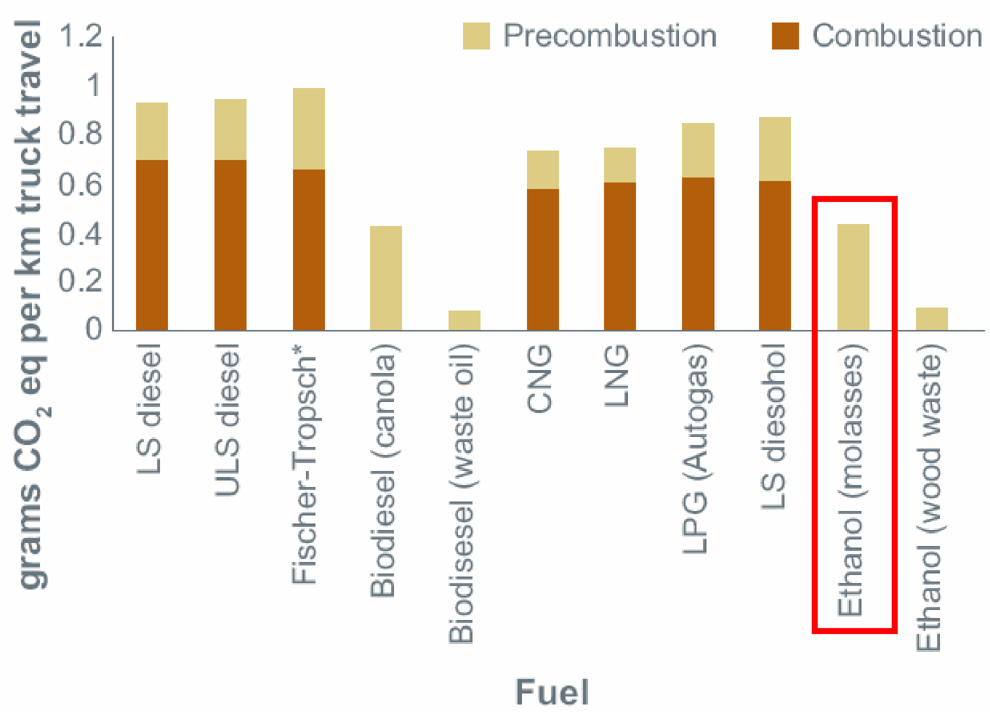
Ethanol fuelled vehicles

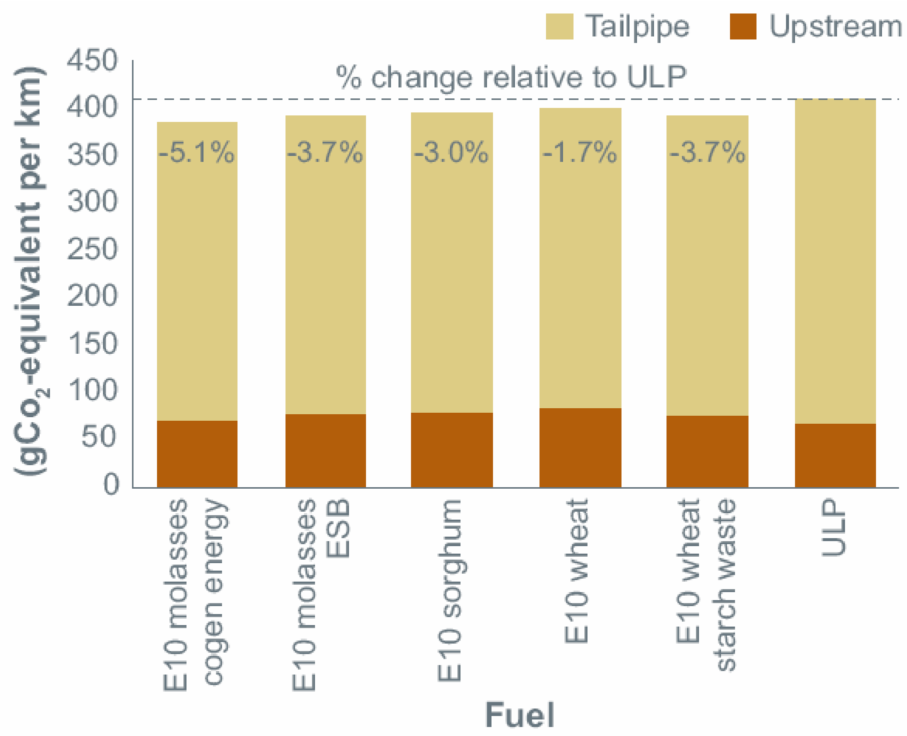
- As with natural gas, ethanol has a higher octane number than gasoline and so high engine efficiencies can be obtained in an optimised engine e.g. [3,12]
- Ethanol's higher heat of vaporisation also enables further increases in compression ratio and so engine efficiency
- This higher efficiency can be used to partially offset the ~30% lower energy content per litre of ethanol relative to gasoline.
- Thus, with a liquid fuel, the loss of range is not normally a problem, unlike CNG.

Property	Gasoline	Ethanol
Molecular Formula	$\sim CH_{1.85}$	C_2H_5OH
C (% mass)	~86.6	52.1
O (% mass)	0	34.7
Density at 20°C (kg/l)	~0.74	0.79
Stoichiometric AFR (:1)	~14.6	9.0
Lower Heating Value (MJ/kg)	~43.5	26.8
Lower Heating Value (MJ/l)	~32.2	21.2
Lower Heating Value (MJ/kg/AFR_s)	~2.90	2.98
CO_2 (g/MJ)	~72.9	71.3
Boiling Point (°C)	25~200	78.4
Latent Heat of Vaporisation (kJ/kg)	~300	855
Research Octane Number	91~98	~110
Ignition Temperature (°C)	~300	420

Ethanol versus CNG/LNG/LPG [8]

- "The greenhouse gas benefits obtained from a renewable fuel such as ethanol or biodiesel are greater than the greenhouse gas benefits obtained from the use of a fossil fuel such as … CNG … or … LPG …. However, the emissions are very sensitive to the feedstock production system and must take into account the complete lifecycle of the agricultural production system."





A route for expanding alternative fuel use?

- Orbital [9] has recently reported that:

  "Using the most recent motor vehicle census (March 2006) and information from the FCAI, the Orbital study estimates that about 7.6 million (60 per cent) of petrol vehicles are suitable for use with E10.

  The FCAI confirms that all new Australian cars are suitable for E10 ethanol blended fuel and that the vast majority of new imported car models sold in Australia today are also compatible with E5 or E10 ethanol blended fuels."

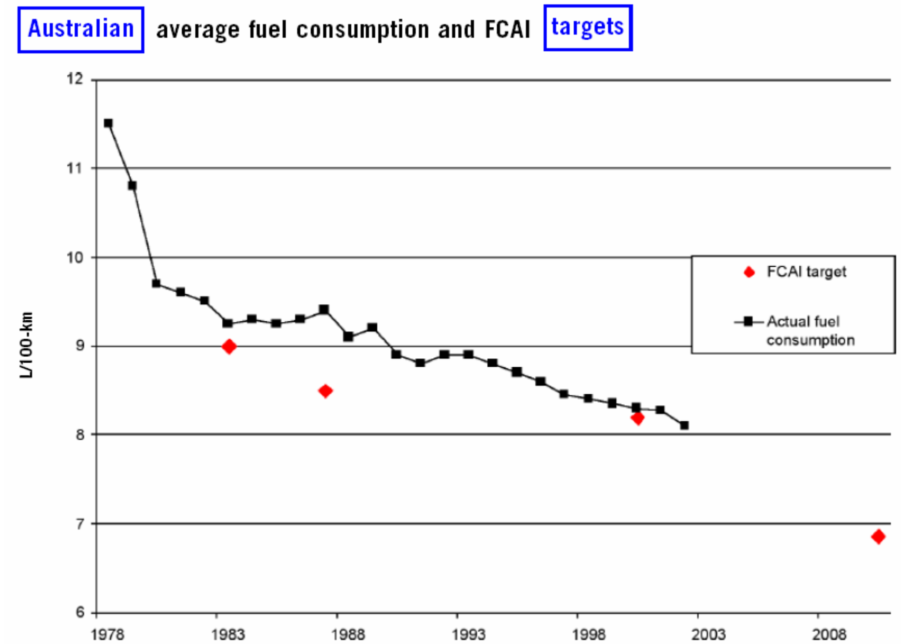
- So a rapid changeover to E10+ is not possible, regardless of GHG emissions.

Further complexity …

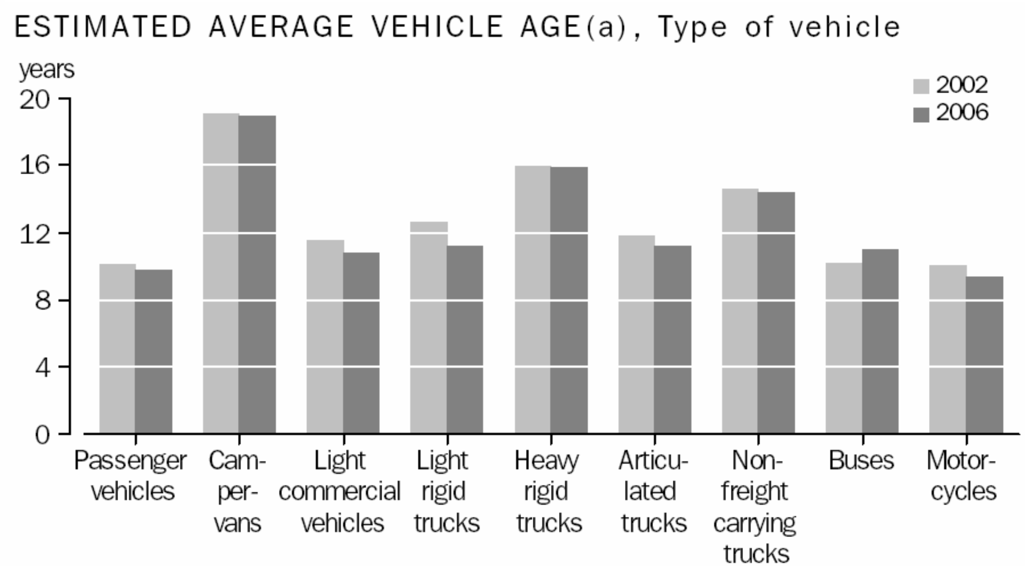
- In order to consider the previously scenario for alternative fuel uptake:

1. In terms of CO_2 emissions, it is rational to purchase a new vehicle when the embedded energy in making that vehicle, plus its improved GHG emissions, achieves lower GHG emissions than the total embedded GHG emissions from keeping your previous, less fuel efficient new vehicle over some estimated future period, i.e. the 'avoided GHG emissions'.
2. Thus, incentives that encourage rapid changeover to lower GHG emitting vehicles could even increase life cycle GHG emissions. It is likely that there will be an optimal rate of vehicle replacement, dependent on many factors including the rate of improvement of fuel economy, the embedded GHG content of the fuel, second hand purchasing patterns and vehicle recycling.

- Such a study has not been performed to our knowledge, and is a complex optimisation problem.



From [1]



From [2]

References

1. An, F. & Sauer, A., 2004, “Comparison of Passenger Vehicle Fuel Economy and GHG Emission Standards Around the World”, Prepared for the Pew Center on Global Climate Change, December 2004
2. Australian Bureau of Statistics, 2006, “Motor Vehicle Census”, 31st March 2006
3. Brewster, S., 2007, “Initial Development of a Turbo-charged Direct Injection E100 Combustion System”, 14th Asia Pacific Automotive Engineering Conference, August 5-8 2007, Society of Automotive Engineers
4. Beer, T., Grant, T., Brown, R., Edwards, J., Nelson, P., Watson H. & Williams, D., 2000, “Life-cycle emissions analysis of alternative fuels for heavy vehicles”, report to the Australian Greenhouse Office, Commonweath of Australia, 2007, “Australia’s future oil supply and alternative transport fuels – final report”, Standing Committee on Rural and Regional Affairs and Transport
5. Bureau of Transport and Regional Economics, 2005, “Greenhouse gas emissions from Australian transport: Base Case Projections to 2020”, Report for the Australian Greenhouse Office (AGO), Department of the Environment and Heritage, August 2005
6. Caesar, W, Riese, J. & Seitz, T., 2007, “Betting on biofuels”, The McKinsey Quarterly, 2007, no. 2
7. Mathews, J.A., 2007, “Prospects for a biofuels industry in Australia”, Maquarie Graduate School of Management working paper no. MGSM WP 2007-13\
8. O’Connell, D. et al, 2007, “Biofuels in Australia – an overview of issues and prospects”, report to the Rural Industries Research and Development Corporation
9. Orbital Australia, 2007, “Assessment of the Operation of Vehicles in the Australian Fleet on Ethanol Blend Fuels”, Report to Department of the Environment and Water Resources, February 2007
10. Rogers, P, 2007, “Recent developments in biofuels”, Farm policy journal, vol.4 , no. 2, May quarter
11. Shapouri, H., Duffield, J., McAloon, A. & Wang, M., 2004, “The 2001 net corn energy balance of corn-ethanol”, Corn Utilization and Technology Conference, June 7-9, 2004, Indianapolis, IN.
12. Turner, J. W. G., Peck, A. & Pearson, R.J., 2007, “Flex-Fuel Vehicle Development to Promote Synthetic Alcohols as the Basis of a Potential Negative-CO2 Energy Economy”, 14th Asia Pacific Automotive Engineering Conference, August 5-8 2007, Society of Automotive Engineers
13. Watanabe, O., Nakajima, S., Goto, H. & Matsunaga, T., 2007, “Development of CNG Engine with Variable Valve Timing Electronic Control”, 14th Asia Pacific Automotive Engineering Conference, August 5-8 2007, Society of Automotive Engineers
14. Watson, H.C., 2007, “Gaseous fuels applications 1) natural gas”, Road Transport Engine Emissions Course, Society of Automotive Engineers Australasia / Advanced Centre for Automotive Research and Testing (ACART)

Brief biographies

Dr. Michael Brear, University of Melbourne

Michael Brear is a Senior Lecturer in the Department of Mechanical and Manufacturing Engineering at the University of Melbourne. His research and teaching are mainly in the fields of combustion, control and thermodynamics. He joined the Department in 2001, having previously completed a Ph. D at Cambridge University and post doctoral research at the Massachusetts Institute of Technology (MIT). Dr. Brear currently collaborates with Alstom (Switzerland), SVW, CERFACS (France), the Ford Motor Company of Australia, Holden Limited and the Orbital engine company. Dr. Brear is also running the University's contribution to the 'Advanced Centre for Automotive Research and Testing (ACART)', which is a new collaborative research centre between the University and the Ford Motor Company of Australia.

Mr. Tony Kitchener, Managing Director, SVW Pty Ltd

Mr. Kitchener has an international reputation in the design and manufacture of several industrial products, and in particular air compressors. He is inventor of the 'Ecoset' screw compressor system, which is patented in Australia, USA, Germany, UK, Japan and licenced to MAN (Germany), Daewoo (Korea) and Stenhoj (Denmark). He was Director of Champion Compressors 1987-94, inventor and developer of integrated screw compressor control systems patented in USA, Europe, Japan and licensed to Ingersoll Rand (world's 2nd largest compressor company). He is also consultant to various compressor companies worldwide including Corac plc (UK), Ateliers Francois (Belgium) and Flair Corp (Japan).

Mr. Kitchener and Dr. Brear collaborate on several research and development projects in the automotive and manufacturing industries. These projects include natural gas driven engines for stationary and transport applications as well as the production and use of ethanol as a transport fuel.