Cost Effective Sustainable Fuels for Performance Vehicles

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14 August 2008

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Prepared in Association With:
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Abstract

Ethanol, as a fuel, has many favourable attributes when considering it for use in general everyday motoring as well as high performance race applications. Its status as a sustainable fuel when sourced from waste or by-product biomass, combined with good combustion, thermal and anti-knock properties, along with a tendency to reduce CO_2 emissions has prompted this investigation into the advantages of petrol-ethanol blends compared to conventional motorsport fuels for use in race vehicles..

This investigation compares three petrol-ethanol blends with three other fuels common to motorsports. Back-to-back testing was carried out on a single engine sourced from the New Zealand V8s National Championship touring car series, fitted with both a carburettor and EFI fuelling systems. Fuel performance was evaluated on cost, consumption, performance, and emissions.

Introduction

An increase in overall green house gas emissions correlating with start of the industrial revolution, coupled with rapidly rising price of crude oil driven largely by a number of political and economic factors, has stimulated new research into the use of bio-ethanol as a sustainable fuel or fuel supplement.

The concept of combining carbon, in the form of hydrocarbons, and oxygen through combustion to release energy and form carbon dioxide is a fundamental component of all internal combustion engine technology used today. Today's challenge relates to the net reduction in CO_2 emissions through the development and adoption of new fuels and optimised engine technology.

This study investigates the performance, cost, and emissions benefits of bio-ethanol as a fuel additive or blending agent in unleaded petrol compared to traditional motorsport fuels with a specific focus on high performance engines tuned for peak power.

Ethanol as a Sustainable Fuel

Traditionally bio-ethanol is produced through the microbial fermentation of sugars into ethyl-alcohol. Recent breakthroughs related to the production of cellulosic ethanol have increased the economic viability of ethanol as a transport fuel. At the same time these breakthroughs are shifting feedstock materials from food crops to agricultural by-products and waste materials creating a higher yielding feedstock and a more sustainable end product.

A major contributing factor driving local investment into new biofuel production technology, techniques, and infrastructure is the stimulation of market demand for sustainable fuels through legislation that incentivises biofuels through tax breaks and credits, and mandatory minimum sales targets for fuel suppliers. Legislation such as this has been adopted by a number of countries worldwide and has proven successful in increasing the uptake of biofuels. The Local Government and Environment Select Committee has affirmed the need for similar legislation in New Zealand. As a result, the Committee recommended an amended version of the Biofuel Bill to Parliament. These amendments will encourage local biofuel production, ensure that biofuels sold in New Zealand provide a significant (35%) reduction in green house gas emissions over fossil fuels, prevent biofuel feedstocks from competing with food production or lands used for food production, and protect indigenous biodiversity and land with high conservation values.

In addition to a considerable net reduction in green house gas emissions, sustainable bio-ethanol can provide a number of additional environmental benefits. Though not measured in this study, other vehicle emissions (namely oxides of nitrogen and sulphur) tend to go down when ethanol is blended with unleaded petrol. There are also additional health and environmental benefits that can be had through the use of bio-ethanol by replacing other anti-knock agents such as aromatic petroleum compounds, tetra ethyl lead (TEL), and methyl tertiary butyl ether (MTBE), an oxygenate and octane improver.

Currently the majority of locally produced bio-ethanol is derived from whey, a dairy industry by-product. At present New Zealand does not have the production capacity to supply enough locally produced bio-ethanol to meet the minimum sales requirements of the Biofuel Bill. It is envisaged that in the short term a portion of bio-ethanol used in petrol blends will be imported from overseas, with Brazil being the likely source.

Brazil is the world's largest supplier of bio-ethanol with over 455 million tonnes of sugar cane grown on over 6.2 million hectares of land specifically for this purpose. A recent study conducted by AgriLINK NZ[1] has demonstrated that ethanol derived from Brazilian sugar cane provides a significant reduction in green house gas (in the order of 74%) emissions over gasoline when landed in New Zealand, and 46% improvement in total energy output compared to gasoline. It is projected that the Brazil's sugar cane planted area could increase by 40% without affecting rainforests or existing lands used for food crops.

Gull Petroleum New Zealand and ExxonMobil are the only suppliers of bio-ethanol blended petrol products in New Zealand at present. Gull service stations supply a 10 percent (98 octane) ethanol blend throughout the North Island, while Mobil services stations in the Wellington region have recently started trialling both 3 percent (91 octane) and 10 percent (98 octane) ethanol blends.

Ethanol as a Performance Fuel

Ethanol has a number of desirable attributes that enable its use as a high performance fuel or fuel additive. Ethanol is renowned for its high octane rating. The higher a fuel's octane rating, the more it will tend to resist pre-ignition or knock, a phenomenon which reduces power output and engine efficiency. With this higher resistance to knock it is possible to achieve much higher compression ratios compared to premium unleaded fuels, leading to better efficiency and increased power.

Ethanol also has a very high rate of combustion and cooler flame temperature relative to many other fuels. This rapid conversion from liquid fuel to expanding gas aids in the production of engine torque, which is desirable in performance vehicles. And its latent heat of evaporation, or the heat energy required to convert the fuel from liquid to gas, is three times that of unleaded petrol. This energy is removed from the engine creating cooler engine operating temperatures and increased efficiency while reducing engine wear. This high latent heat of evaporation also allows the fuel to remove heat from the intake air charge resulting in cooler more dense air entering the engine adding to further

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[1] *The sustainability of Brazilian Sugarcane Bioethanol,* A Literature Review

increased engine efficiency. Recent studies out of Japan have shown that ethanol, even when blended with unleaded petrol in relatively low quantities, can prevent the formation of deposits on fuel injectors that would otherwise reduce performance and efficiency[2]. One drawback to ethanol is its reduced specific energy content, that being roughly 65% of unleaded petrol. Despite this, and as a result of ethanol's lower air fuel ratio, (approximately 6.5:1 and 12.5:1 respectively for ethanol and unleaded petrol when tuning for power) the theoretical heat energy produced will increase by approximately 28% over unleaded petrol. Carbon dioxide exhaust emissions when using ethanol tend to remain much the same as unleaded petrol, varying slightly with changing engine speeds and loads.

Test Fuels

For this study six fuels were selected, three being more conventional fuels used widely in all types of motorsport, and three that incorporate a varying percentage of bio-ethanol. Table 1 shows the general properties of the test fuels used in this study. Shell Racing Fuel 100 Plus was supplied from Shell New Zealand Ltd. BP Ultimate 98 unleaded was supplied from a local BP service station. VP Fuels MS109 was imported by Pioneer Autoparts Ltd. Gull Force 10 E10 was supplied from a local Gull service station. Anhydrous Methylated Spirits (AMS), bio-ethanol denatured with 2% methanol, was supplied from Polychem Marketing Ltd. BP Ultimate 98 unleaded petrol was blended with AMS to achieve the E50 and E85 fuels.

CONVENTIONAL MOTORSPORT FUELS

Shell Racing 100 Plus, or Avgas 100 as it is sometimes referred to, being a particular type of aviation fuel used in piston engine aircraft, is a 100 octane (MON) minimum specialty racing fuel which uses TEL as an anti-knock agent. TEL is also a very harmful neurotoxin that can affect children in low quantities or cause hallucinations and death in higher concentrations.

BP Ultimate 98 unleaded fuel is widely available throughout New Zealand. It is manufactured through the fractional distillation of crude oil, and the conversion of the low

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[2] *Feasibility Study of Ethanol Applications to A Direct Injection Gasoline Engine,* SAE Paper

octane gasoline fraction into high octane aromatic components such as benzene, toluene, xylene, which improve knock resistance.

VP MS109 is a specialty high performance motorsport fuel. The exact composition of this fuel is protected by the manufacturer. However, it is known to contain high levels of MTBE. MTBE has not been confirmed as a human carcinogen although it is suspected to have carcinogenic effects when exposure occurs at high levels. Because of its high persistence and solubility in water, small quantities of MTBE have the ability to render large amounts of ground water non-potable. As a result California and New York State banned MTBE in 2004. They were joined by 23 other states the following year.

BIO-ETHANOL BLENDED FUELS

Gull Force 10 is a 95 octane unleaded petrol blended with up to 10% bio-ethanol or E10. It was the first retail gasoline product containing a biofuel component available in New Zealand.

E50 used in this study was blended from 50% AMS and 50% BP Ultimate 98 unleaded petrol by volume.

E85 used in this study was blended from 85% AMS and 15% BP Ultimate 98 unleaded petrol by volume.

Table 1: Fuel Properties

Fuel	Shell Racing Fuel 100 Plus	BP Ultimate 98 Unleaded	VP MS109	Gull Force 10 (E10)	E50	E85	AMS
RON	105-110	99.6	109	99.2	105.5	109.7	111.5
MON	100-102	86	101	87.7	88.5	90.25	91
Density (g/cm^3)	0.69	0.75	0.722	0.74	0.77	0.784	0.79
Heat Energy (J/l)	-	33.15	-	32.34	28.75	25.66	24.34
RVP (kPa)	38-49	50-95	42.5	100*	-	-	15
Aromatics (%)	Nil	26-42	-	41.4	13-21	3.9-6.3	Nil
Oxygenates (%)	0.1	Nil	-	7.95	49.95	84.91	99.9
Lead (gPB/l)	0.85	Nil	Nil	Nil	Nil	Nil	Nil

*Dry Vapour Pressure Equivalent ASTM D 5191

Method

The engine selected for this study was a conventional spark ignition engine found in Holden Commodores competing in the New Zealand V8s National Championship touring car series. The engine is a 304ci (4980cc) pushrod style V8. The NZ V8s control part Harrop dual plane intake manifold was used with both the carburettor and the electronic injection fuel systems. The NZ V8s control part Demon 600cfm carburettor was replaced by a 1000cfm MSD throttle body for the EFI system tests. Engine performance was optimised through fuel mapping or jetting and adjustment of the ignition timing. All other aspects of the engine remained constant throughout testing. Specifications for this engine are detailed in Table 2.

Engine power and torque were measured at partial load and wide open throttle (WOT). Consumption and emissions were measured under load where power and torque are maximum with WOT.

Table 2: Engine Specifications

Number of Cylinders	8
Bore X Stroke	101.59mm X 76.96mm
Compression Ratio*	10.0:1
Displacement	4980cc
Carburettor	Demon 600cfm four barrel
Fuel Injection System	MPI
Valves per Cylinder	2
Intake Valve Lift & Dura.	.0293" @ 229°
Exhaust Valve Lift & Dura.	.0293" @ 229°

*Compression ratio is a maximum value detailed in Schedule TL, Technical Regulations for the NZ V8s

Results and Discussion

Figure 1 shows peak power for each fuel in both fuel delivery systems at 6400RPM under load.

All fuels tested in the EFI system showed an improvement over Shell 100. E50 and E85 show the most significant power gains of 3.7% and 4.7% respectively over Shell 100 in the EFI system. These gains are surprisingly modest compared to the significant increase in fuel consumption necessary to achieve adequate air-fuel ratios. This can be linked to two likely contributing factors, namely injector location relative to the inlet valve, and a reduction in volumetric efficiency (VE). Typically, as a result of its high latent heat of evaporation, an increase in VE will occur when ethanol is used. This gain in VE is due to ethanol's high latent heat of evaporation, which has a cooling effect on the air charge entering the cylinder. However, if the ethanol is injected too close to the valve then its ability to cool the intake charge will be significantly reduced. Subsequently this inability to effectively transfer heat from the intake air to the ethanol will inhibit the atomisation of fuel as it enters the cylinder

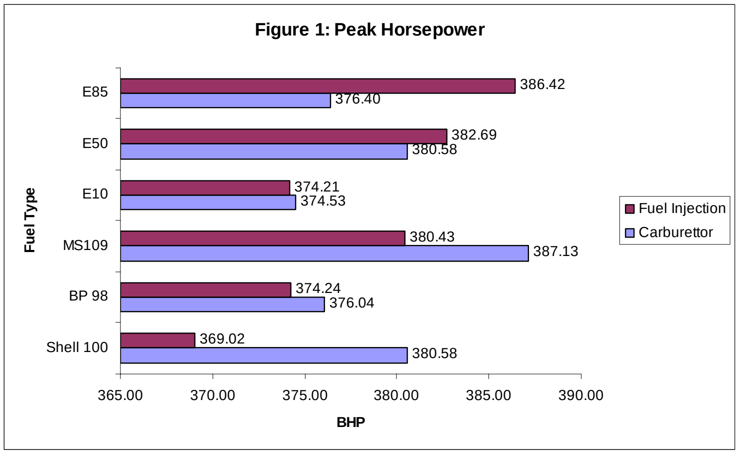


Figure 1: Peak Horsepower

MS109 was the only fuel to show a power gain in the carburetted system with a modest 1.7% increase over Shell 100. E50 has comparable performance to Shell 100 in the carburetted system despite a 19% increase in consumption, although, due to the disparity in heat energy, actual energy consumption between the two fuels is likely to be on par. There was, however, a marked reduction in performance with the E85 in the carburetted system. It is likely that the carburettor and inefficient intake manifold were unable to supply properly atomised fuel when fuel density and consumption exceeded 0.75g/cm^3 and 2 l/min respectively.

All fuels except E50 and E85 displayed an increase in power output in the carburettor over the EFI system. Consumption in the carburettor increased compared to the EFI system for all fuels except E85. This would indicate that the carburettor and intake manifold favour fuels of a lesser density with a higher latent heat of evaporation giving gains in VE and overall output.

Figure 2 shows fuel consumption at peak power. Shell 100 in the EFI system gives the lowest consumption rate overall at 1.30 l/min. BP 98 and Gull E10 give similar consumption figures at 1.35 l/min and 1.40 l/min respectively. Gull E10 and BP 98 give the lowest consumption rates in the carburettor at 1.7 l/min. E85 gives the highest consumption rate in both fuel systems. Consumption increases over Shell 100 129% and 38% for E85 in EFI system and carburettor respectively.

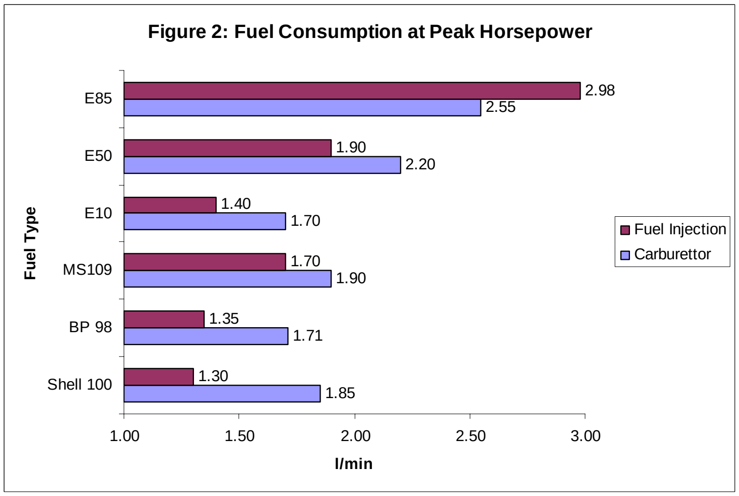


Figure 3 shows CO2 emissions as a percentage of total exhaust gas measured at peak power. Shell 100 in the carburettor and BP 98 in the EFI system show the lowest percentage of CO2 emissions at 9.6% and 9.7% respectively. E50 and E10 give the highest percentage of CO2 emissions at 11.2% and 11.4% respectively. All other fuels' measured exhaust CO2 content is within 0.3%. MS109 was omitted due to an error in the data recording system which resulted in inconsistent data.

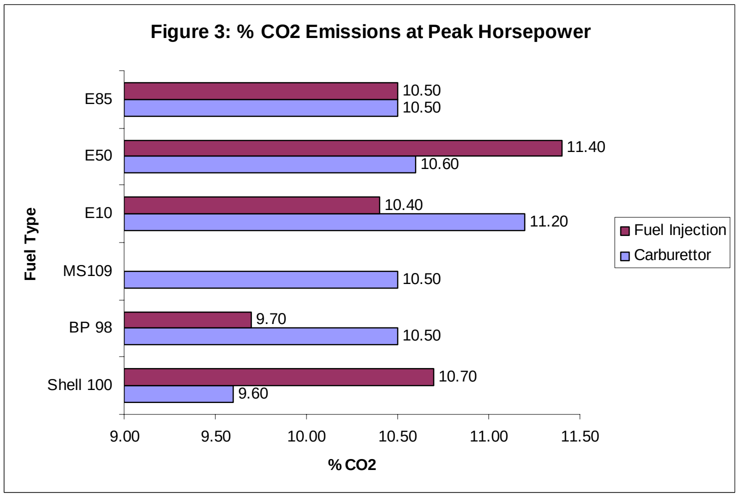
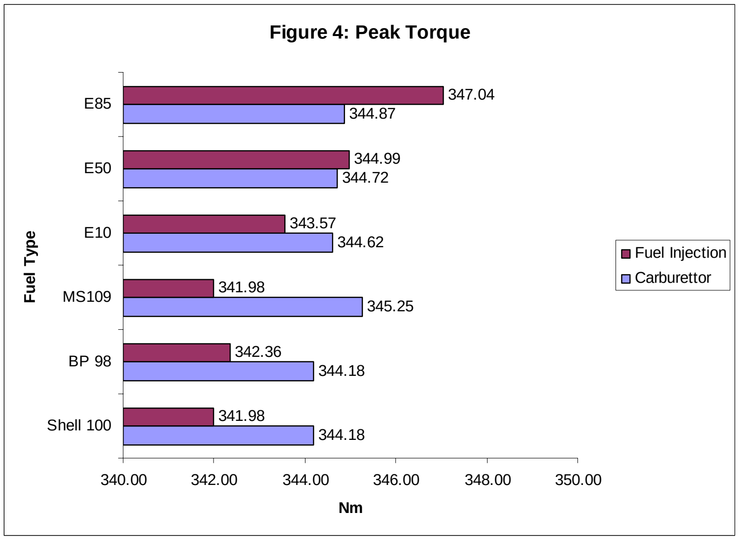


Figure 4 shows peak torque for each fuel. In all cases peak torque occurred between 4000RPM and 4500RPM. The carburettor produces the most consistent and flattest torque curves for all fuels tested except E85. As expected the ethanol blends, especially the high percentage blends, performed well in the EFI system. At lower engine speeds the valves are open longer giving more time for fuel to enter the cylinder. This combined



with high combustion speed of the ethanol provides good torque figures compared to other fuels.

Figure 5 shows the rate of fuel consumption at peak torque. Shell 100 and BP 98 in the EFI system give the lowest consumption at peak torque at 1.7 l/min. Gull E10 gives comparable consumption figures to Shell 100 and BP 98 in both fuel systems. However, a slight increase in peak torque can be seen for this fuel.

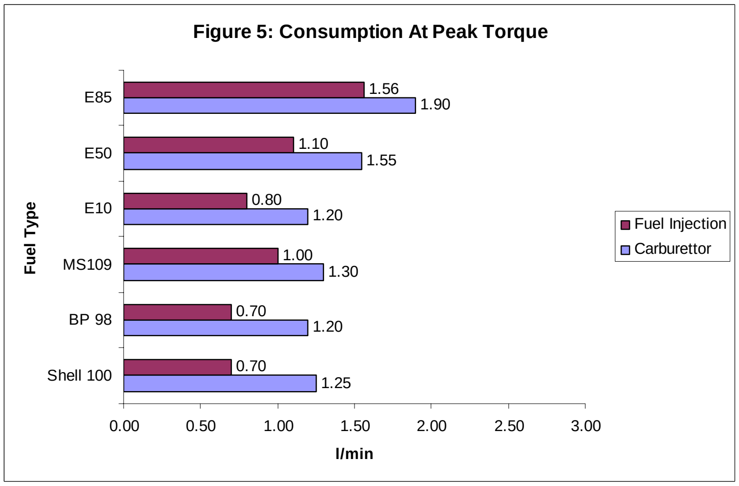
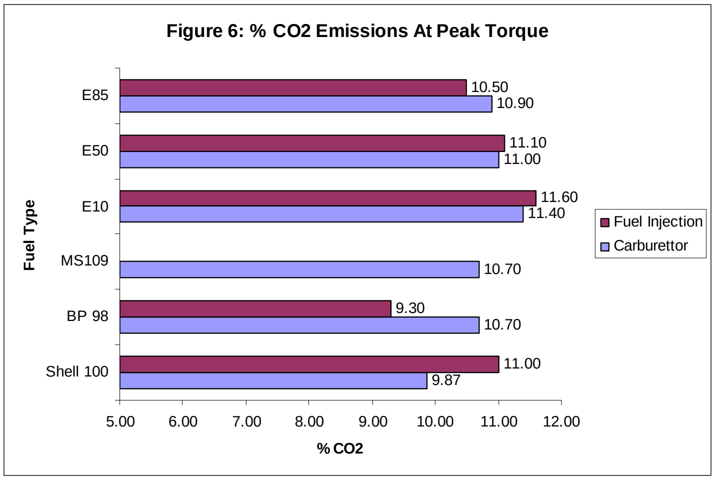
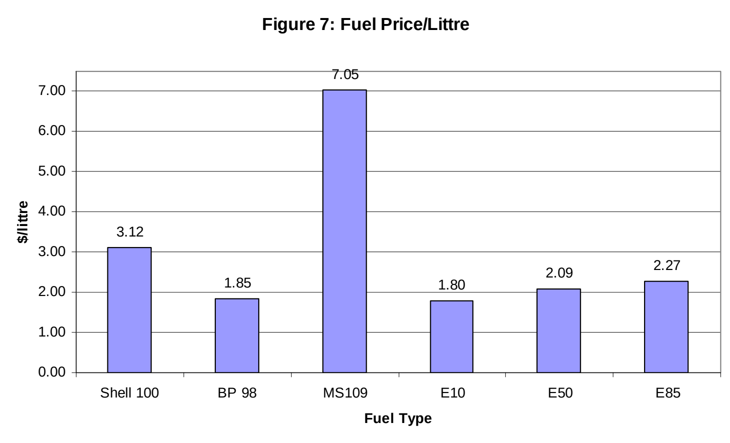


Figure 6 shows CO_2 emissions as a percentage of total exhaust gas measured at peak torque. Shell 100 in the carburettor and BP 98 in the EFI system again show the lowest percentage of CO_2 emissions at 9.87% and 9.3% respectively. E10 gives the highest overall percentage of CO_2 emissions at 11.6% and 11.2% for the EFI system and carburettor respectively. All other fuels measured exhaust CO_2 content is within 0.4%. Again emissions data for MS109 was omitted for reasons previously stated.



Financial Implications

A major component of this study was to compare fuel cost relative to performance. Figure 7 shows a comparison of fuel cost as purchased including all applicable taxes and duties in NZD. MS109 was by far the most expensive fuel tested at 2.25 times the cost of Shell 100. E10 was the least expensive at $1.80/litre. The AMS used to blend the E50 and E85 fuels was purchased at $2.34/litre. All fuels used in this study except for E50 and E85 blends are commercially available mass produced products for retail sale. As a result the price of E50 and E85 are higher then what would be expected if the fuels were being mass produced. Consequently the Horsepower/$ and Torque/$ graphs shown in Figures 8 & 9 indicate these fuels perform poorly when assessed on a cost basis. In fact



this is not the case at all and a 10% price reduction on the AMS component of these is all that is required for E50 to surpass Shell 100.

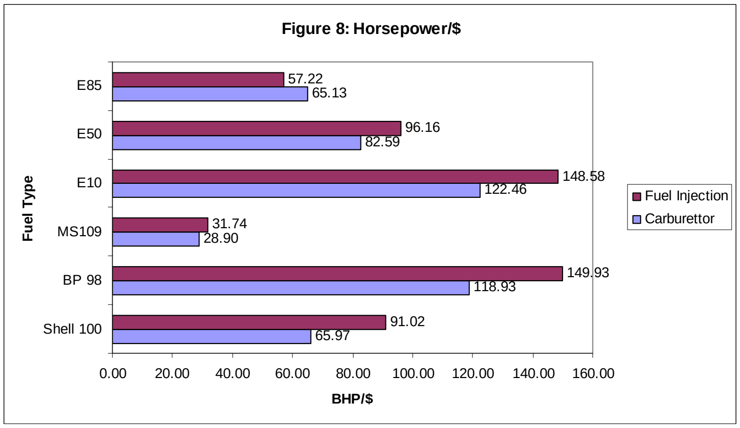


Figure 8: Horsepower/$

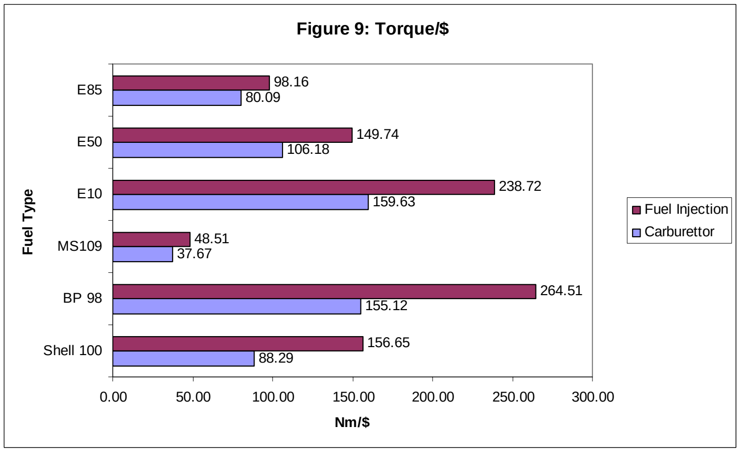


Figure 9: Torque/$

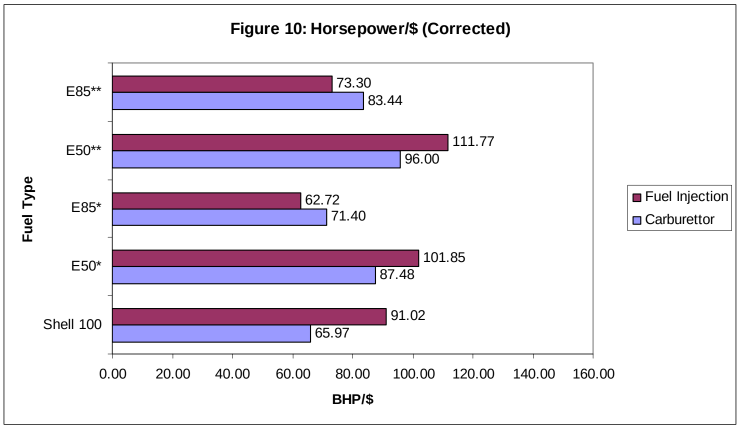


Figure 10: Horsepower/$ (Corrected)

* Represents a 10% reduction in the price of AMS

** Represents a 25% reduction in the price of AMS

Conclusion

Bio-ethanol used in a high percentage blend or as a fuel additive provides distinct performance advantages over conventional fuels. Ethanol provides increased knock resistance, thermal efficiency, and improved power and torque. It is expected that even higher performance gains could have been made with additional changes to the test engine.

Although the scope of this study covered exhaust emissions it took no account of net greenhouse gas emissions saved as a result of carbon dioxide absorbed in the growth of bio-ethanol feedstocks. The study also did not allow for any fuel specific optimisation beyond that of fuel delivery and ignition timing. Nevertheless, all of the ethanol blends showed gains in power or torque over the conventional motorsport fuels in at least one of the fuel systems tested.

At both peak power and peak torque, consumption for E10 remained comparable to conventional motorsport fuels while providing comparable power and improved torque figures. E10 was also the least expensive fuel tested, providing the best performance per dollar when in the carburettor and second best performance per dollar in the EFI system.

The higher percentage ethanol blends also showed good performance per dollar with minimal reductions to the price of AMS. Additional power and efficiency gains would be expected with optimised fuel delivery systems and a compression ratio in the range of 12:1 to 13:1.

Exhaust carbon dioxide emissions for ethanol blends in this engine were comparable to the conventional motorsport fuel emissions, though recent studies have confirmed the sustainable nature of bio-ethanol used in blended petrol products currently available in New Zealand. As a result, over the life cycle of the fuel, even when used in low percentage blends, ethanol is expected to cause a measurable reduction in overall CO_2 emissions.

Acknowledgements

The Author would like to acknowledge the EECA Biofuels Consumer Awareness Group, MSNZ Executive Committee, Ross Armstrong, Julian Leach, Rex Harrison, Richard Moss of MotorSport Electronics, Randle and Tim Edgell, Rex Clark, and David White.

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