ETHANOL AS A PETROLEUM EXTENDER AND ADDITIVE IN AUTOMOTIVE ENGINES

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Abstract

The history of ethanol-petrol blend application is summarised. Past and future changes in the design of automotive engines are outlined. The properties of ethanol and petrol and their blends are compared. Early and recent reports on the performance of ethanol blends are summarised. The oil crisis coupled with the fact that likely contenders to replace present engines will operate efficiently on alcohol confirms that there is a future role for ethanol. There is considerable evidence from recent experience in Brazil and the U.S.A. to confirm that ethanol blends up to 20 percent can be used without problems in spark ignition engines. Up to 15 percent, ethanol-diesel oil blends also appear to give no problems provided a blend stabilising agent is added. A close liaison with oil companies is proposed in order to optimise blend formulations. Credits for certain advantages of ethanol such as its antiknock value would already appear to justify the use of blends of 10 percent ethanol produced from enriched molasses. The situation appears of sufficient economic interest to justify a more detailed study under local conditions.

Introduction

In the past two decades the local price of petrol has increased by 400 percent and this coupled with the realisation that petroleum oil is a finite resource has led to economising measures. While we are fortunate in South Africa to have abundant coal reserves these are also finite and particularly so in the form of liquified fuel due to the enormous capital cost involved. Against this we have a rapidly increasing and increasingly sophisticated population whose demands for automotive transport seem likely to escalate in the absence of adequate public transport facilities while motor manufacturers appear reluctant to change to alternatives which would dramatically reduce projections for future liquid fuel demands.

The scenario is one which leads inevitably to the consideration of renewable fuels of which ethanol from sugar cane (or molasses) would appear to be one of the most attractive, having a positive net energy balance. This paper aims at summarising the technical and economic aspects of the application of ethanol in petroleum blends and in particular the possible advantages of ethanol blends are considered against the present higher cost of production.

Past use of Ethanol Blends

The consideration of ethanol as fuel dates almost to the advent of the internal combustion engine[14]. This was due to the favourable physical properties and almost universal availability of alcohol.

Attention was soon turned from alcohols to hydrocarbons due to their low cost and potentially abundant supply. After the first world war the universal trend towards national self-sufficiency in fuel and the need to expand agriculture revived interest and power alcohol became an important aspect of agricultural programmes in many countries. By 1936 the world consumption of power alcohol (largely ethanol) exceeded 800 megalitres per annum. Oil shortages during the second world war and consequent petrol rationing in many countries created further interest in alcohol fuels in many countries especially those producing sugar. For example alcohol-ether-petrol blends were produced in Brazil and South Africa (the latter called Natalite). During the war although the largest quantity of ethanol was devoted to explosives and other war materials special applications were also made of the ability of alcohol-water mixtures to dramatically increase the power output of super-charged piston type aircraft engines.

The National Alcohol Campaign in Brazil probably had its roots in the post-war research into alcohol fuels which began in 1951 after the Motors Research Laboratory began operation at Aerospace Technical Centre outside Sao Paulo.

In South Africa a 1:1 ethanol:petrol blend (Union Motor Spirit) became popular because of its favourable anti-knock characteristics. The blend was normally mixed with petrol in a 3:1 ratio (petrol:Union) giving a final 12,5 percent ethanol blend. Many motorists used this mixture (and even higher ratios) without any engine adjustments. Minor problems were sometimes experienced in the switch from petrol to ethanol blend due to the solution of petrol resin deposits blocking fuel filters or jets. In addition some inferior quality petrol pump diaphragms perished under the action of ethanol. However, this problem was solved when laboratory trials showed that the ammoniation of Union in order to neutralise traces of organic acids in the ethanol generated more corrosive nitrogenous compounds and the ammoniation was discontinued. At the same time a 10 percent ethanol-shale oil-petrol blend was marketed on the Reef under the name of Satmar. Apart from the unpleasant odour of the fuel and its products of combustion it was also popular for its antiknock value.

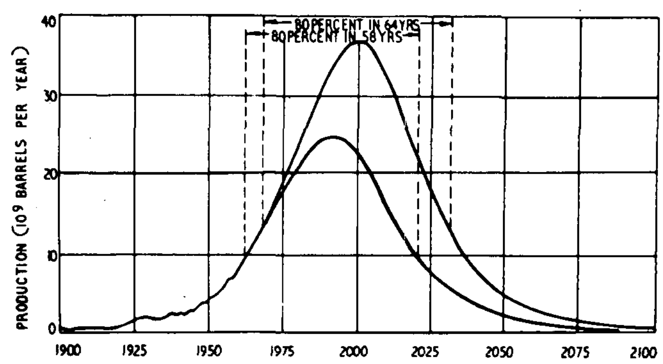

FIGURE 1 Cycle of world oil production, 1900–2100

With the advent of the high octane premium petrol grades the use of ethanol blends for the suppression of engine knock was gradually discontinued during the 1960's. The petrol alone had a high enough octane rating to cope with the modern high compression engine. The disinterest in alcohol fuels was short-lived. During the 1970's political and economic factors have led to an increased awareness of the finite nature of the world's fossil fuel reserves. Studies of past

TABLE 1

Measured (estimated recoverable) reserves for principal resource regions (energy content in millions of terajoules)

	Solid Fossil Fuels	Crude Oil	Natural Gas	Oil Shale and Tar Sands	Uranium (Non Breeder)	Total without Breeder	* Uranium Thorium (with Breeder)
Africa	500	550	200	100	200	1 450	12 550
Asia	2 750	2 350	450	900		6 450	200
Europe	2 600	>50	>150	>100	50	3 000	9 750
U.S.S.R.	3 500	350	600	150	—	>4 600	>3 400
U.S.A..	5 200	250	300	6 360	300	12 400	19 750
Canada	150	50	100	3 250	150	3 700	13 750
South America	50	350	50	<50	—	500	3 750
Australia	500	—	<50	—	100	600	6 250
World	15 100	3 950	1 950	10 900	800	32 750	66 100*

* Use of uranium in breeder reactors would increase its usable energy content 60-fold, which with thorium would treble total usable world reserves.
(*From:* World Energy Conference Survey 1971)

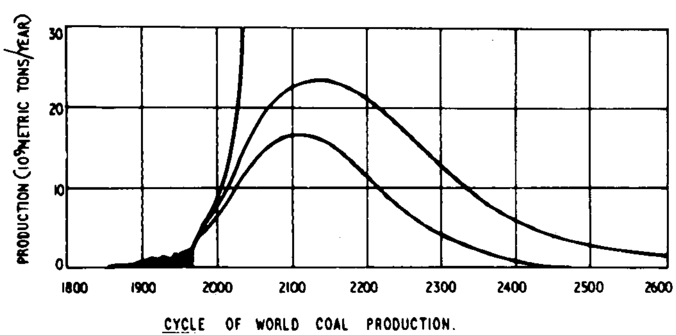

FIGURE 2 Cycle of world coal production, 1800–2600

trends and future predictions for oil and coal consumption (Figures 1 and 2) indicate that oil peaks before coal, although the exact timing will depend on conservation measures[12]. The crossover point where coal takes over from oil will probably occur early in the next century. The present reserves of fossil fuels (measured and estimated) are shown in Table 1 while these are expressed in Table 2 in terms of the ratio of recoverable reserves to the 1971 consumption rate giving an estimated life[12]. This is based on current technology and economics and is therefore conservative. However, it does give a clear indication that future fossil fuel energy is going

TABLE 2

Ratio of recoverable reserves of fossil fuels to 1971 Consumption for principal producing or consuming regions
(From World Energy Conference Survey 1974)

Africa (Total)		352
Western	398	
Eastern	172	
Middle	1 192	
Northern	870	
Southern	149	
Asia (Total)		201
China	264	
Japan	3	
India	95	
Middle East	1 155	
Iran	682	
Europe (Total)		54
Western	58	
Northern (Incl. U.K.)	25	
Southern	40	
Eastern	85	
U.S.S.R.		144
U.S.A.		180
Canada		607
South America		100
Australia		256
New Zealand		88
World		156

to escalate in price not just due to scarcity but also due to increasingly sophisticated technology necessary to exploit dwindling reserves.

It is this thinking which has revived the interest in alcohol fuels; methanol as an attractive liquid fuel which can be produced from coal and ethanol an attractive liquid fuel which can be produced from renewable plant material such as maize and cane. In Europe research into the use of methanol-petrol blends is widespread, particularly in Germany[6]. At present the use of ethanol blends is prominent in Brazil where VW has a research team with a $2 million budget. In Sao Paulo and Rio de Janeiro the ethanol blend has reached 20% with current ethanol production around 2 billion litres for 1979 (3 billion for 1980 and 4 billion for 1982). Several fleets of cars are used on a continuous test run e.g. a telephone company has a fleet operating on straight ethanol. In the United States a 10 percent unleaded ethanol blend "Gasohol" is marketed in Iowa and Nebraska, the former from molasses and the latter from grain. A fleet of 45 cars has been on a 2 million mile test since 1974 and the blend is on sale with state taxes subsidised and national subsidies under consideration. A series of comprehensive reports has been published by Scheller[19]. While in South Africa the use of Union Motor Spirit has dwindled, it is reported that motorists have unknowingly been using ethanol blends produced by SASOL[5]. Tests on methanol blends are currently being conducted by the University of Cape Town and on ethanol by the University of Natal.

Periodic resumés have been published by the American Petroleum Institute (API) and while earlier comments have been critical[1], it is evident that the looming fossil fuel crisis is tempering their more recent thinking[2] leading to more respect for alcohols as a fossil fuel extender. A study of the literature cited will indicate that it has been a tendency in the past for oil companies to draw out the possible problems associated with alcohol blends with some confusion between ethanol and methanol for the unwary reader while chemical companies with an interest in the exploitation of potential future fuel production have adopted the opposite tactic. For this reason an inexperienced reader is likely to be thoroughly confused by the literature even without the added complication of changes in engine design since the second world war. For this reason it is advisable to concentrate on more recent published tests in the assessment of alcohol blends.

Design trends in automotive engines

In order to establish the continued need for liquid fuels similar to those presently in use it is necessary to examine the motor industry philosophy. In 1970 prior to the emission legislation the U.S.A. consumed one third of the world's energy production (half in the form of oil). Just over half of the U.S. oil was used for transport with nearly a third in private cars. (About a quarter of the non-oil energy was used to manufacture these cars). The fuel consumption in cars modified to meet emission legislation increased by 20 percent and could rise to over 30 percent if further proposed legislation is enacted. It has been argued that increased use of telecommunications and public transport would reduce fuel consumption. However, it is generally considered that the private car because of its flexibility will remain the most desirable form of personal transport, at least during the period during which oil conservation is important, unless totalitarian measures are adopted to price it off the market[18].

The relative importance of parameters likely to influence the trend of passenger car engines in future[18] is shown in Table 3. This represents the position in 1973 but the arrows indicate that fuel consumption and noise will rise to the level of importance of emissions in the 1980's. This table also indicates the attributes of the most likely contenders to supplement today's piston engines. The stratified charge engine is considered to be the leading near-term contender while the Stirling engine followed by the turbine are considered to be the leading long-term contenders. The range of expected market penetration[18] is shown in Figure 3. Stirling and turbine engines are expected to take over from the Wankel with a reduction in catalytic exhausts as the stratified charge engine takes over.

TABLE 3
Relative Importance of Selection Parameter

Passenger Cars — Compared with 4-Cycle Spark Ignition Piston Engine

	Wankel	*Turbine	Stirling	Stratified Charge	Diesel
Flexibility	–	+	+	0	–
Smoothness	+	++	++	0	–
Emissions	0	+	++	+	+
Cost	–	–	–	?	–
Noise	0	+	++	0	–
Weight	+	+	0	–	–
Size	+	0	–	–	–
Maintenance	0	+	+	0	+
Fuel Consumption	–	–	++	+	++
Durability	–	?	+	0	+

Advantage (+) or Disadvantage (–) *Two-Shaft Regenerative 1900 F Turbine Inlet Temperature

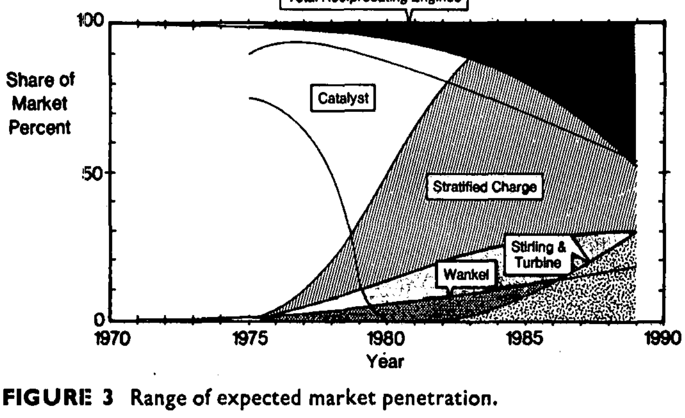

FIGURE 3 Range of expected market penetration.

All of the above possible contenders for existing engine replacement would operate successfully on both ethanol and methanol[5] and would show advantages over petrol in terms of improved efficiencies and emission levels. The history of the motor industry has been one of evolutionary not revolutionary change. For example the switch to high compression overhead valve short stroke engines started in 1948 and was completed only in 1966. Prior to that the last previous new engine was introduced 17 years earlier. Although the fuel crisis is bound to generate new ideas it is generally considered that liquid fuels are going to be in demand for automotive engines for the foreseeable future and this includes alcohols as well as petrol.

Properties of ethanol

In order to provide a more meaningful comparison of ethanol[1] and petrol the general properties of methanol are also included in Table 4. The fact that the heating value for alcohols per litre in the tank is lower than for petrol is frequently used as a criticism. In fact there is a tendency to quote costs in terms of per unit of heating value thus totally disregarding the efficiency of conversion of heat into work. The higher flash points for alcohols are also criticised as indicative of poor cold start characteristics while the higher initial boiling temperature and latent heat of vaporisation is blamed for vapour lock and inferior driveability.

The properties of ethanol blends[9] are shown in Table 5. This indicates a far less drastic departure for blends up to 20 percent. Two other characteristics of alcohol blends are worth noting. The Reid vapour pressure of ethanol blends increases up to 40 percent. This is taken by critics as an indication that vapour lock problems will occur particularly in the case of methanol blends. The water tolerance is the second outstanding point which should be noted. The data in Table 5 indicate water holding capacities of ethanol blends (before phase separation). For comparison the water tolerance of a 10% ethanol blend at 20°C is 0,35 percent against about 0,15 for the equivalent methanol blend.

Performance of ethanol blends

Economy

Fuel economy is linked to engine tuning and since motorists are beginning to accept the need for economy checks the tuning on an engine when switching to an alcohol blend will not be regarded as onerous. The properties of ethanol including its relatively lower heating value and higher air ratio for complete combustion may require minor resetting of the carburettor with ethanol blends in order to maximise fuel economy but it has been concluded[2] that alcohol blends give the same economy as petrol at the same mixture strength. However tests conducted more recently in Brazil (Figure 4) have indicated that with the normal petrol settings a slight improvement in economy is experienced with increasing blend concentration and this breaks even at 15 percent[20]. Up to 20 percent very little loss of economy is experienced. With optimum ethanol settings there is no significant loss of economy until 40 percent blend is exceeded. These conclusions have been confirmed using a fleet of various Brazilian cars.

In Nebraska a 3 million km test on a fleet of 45 cars was conducted from December 1974 using Gasohol fuel, a 10 percent ethanol blend with unleaded petrol. The tests were controlled by the Department of Chemical Engineering, University of Nebraska[19]. It was found that at temperatures below 20°C there was an improvement in volumetric fuel economy of up to 4 percent over the unleaded petrol,

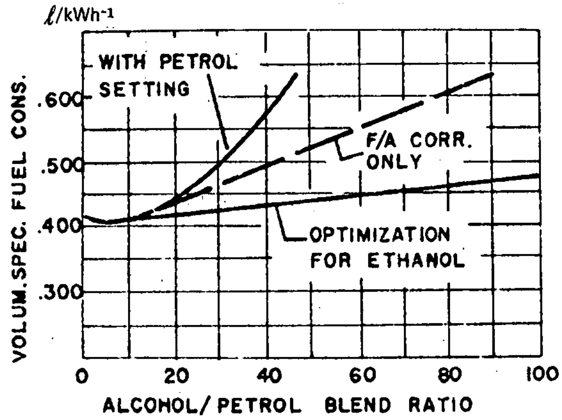

FIGURE 4 Volumetric specific fuel consumption for various blend ratios without petrol engine modification up to 20%, and with engine optimization.

These observations confirm numerous other tests conducted earlier to the extent that there is no serious decline in fuel economy using standard engines and blends up to 20 percent[9].

Power

Since the stoichiometric air/fuel ratio is much higher for petrol than for ethanol (Table 4) it would theoretically be expected that in an engine set for petrol the introduction of an ethanol blend would lead to a leaning effect with a drop in power and carbon monoxide emissions. Research has in fact shown an increase in power output and a drop in emissions[8]. The explanation for this result is that the higher latent heat of vaporisation of alcohol results in a greater mass of charge per cylinder due to the reduced temperature of the inlet gas. It is also possible that the lower flame temperature and slower rate of flame propagation may have more

TABLE 4
General properties of alcohol and petrol

Property:	Methanol	Ethanol	Petrol
Formula:	CH_3OH	CH_3CH_2OH	Mixture of C_4 to C_{12} Hydrocarbons
Molecular weight	32,04	46,07	100–105 avg.
Composition, weight per cent:			
Carbon	37,5	52,2	85–88
Hydrogen	12,6	13,1	12–15
Oxygen	49,9	34,7	0
Specific gravity, 15,5° C / 15,5° C (24° C / 4° C)	0,796 (0,787)	0,794 (0,785)	0,72–0,78 (0,741)
Density l/ton	1256 (1271)	1259 (1274)	1333 (1351)
Boiling temperature °C	65	78	27–255
Flash point ° C	11	13	–43
Autoignition temperature ° C	464	423	257
Flammability limits, volume %:			
Lower	6,7	4,3	1,4
Higher	36	19,0	7,6
Stiochiometric	12,3	6,5	2,0
Stoichiometric air/fuel ratio (kg/kg)	6,45	9,00	14,7
Lower heating value at 20° C:			
MJ/l	15,77	21,09	32,17
GJ/t	19,81	26,56	42,89
Latent heat of vaporisation at 20° C:			
MJ/l	1,90	1,35	0,48
Reid vapour pressure of 10% blend mbar against petrol	700	570	510

TABLE 5
Summary of physical-chemical properties of alcohol blends

C_2H_5OH Content per 100 cc Blend	Water Holding Capacity per 100 cc Blend			Water Absorption per 100 cc Blend		Evapn. loss by Wt[c]			Reid Vapor Pressure (Dry)	Sp. Gr. 25/4°C	Fluidity at 25°C	Air-Fuel Ratio for Complete Combustion by Wt	Calorific Value *Lower* including Latent Heat at Constant Vol	Latent Heat of Evapn. at Atm.	Fall in Temp. on Evapn. of Correct Air-Fuel Ratio
	−20°C	0°C	+20°C	a	b	1 hr	3 hr	17 hr							
cc	cc	cc	cc	cc	cc	%	%	%	m bar				Cal./cc	Cal./cc	°C
0	0	0	0	0	0	6,0	11,5	27,0	529	0,7212	215,3	14,8	7700	54,5	18,8
1	0,008	0,013	0,019	0,010	0,005	6,3	12,2	28,3	...	0,7214	218,9	14,7	7675	54,5	19,4
2	0,018	0,030	0,043	0,014	0,018	6,3	11,3	29,5	...	0,7217	219,1	14,7	7650	56,5	20,0
4	0,045	0,080	0,104	0,061	0,014	7,8	13,3	32,7	529	0,7225	217,6	14,6	7600	58,5	21,2
6	0,080	0,131	0,180	0,101	0,008	6,4	12,9	33,3	...	0,7236	214,5	14,5	7550	60,5	22,4
8	0,112	0,188	0,261	0,148	0	6,4	13,5	35,5	549	0,7246	213,9	14,3	7510	62,5	23,6
10	0,150	0,245	0,347	0,218	0	5,5	10,9	34,5	590	0,7257	207,6	14,2	7470	64,8	24,8
15	0,251	0,417	0,589	0,838	0	5,4	11,6	32,1	611	0,7292	200,6	13,9	7450	70,5	27,9
20	0,355	0,589	0,832	0,396	0	5,3	11,3	32,3	605	0,7323	191,6	13,6	7240	75,8	30,8
30	0,541	0,938	1,357	0,550	0	4,5	11,6	28,6	611	0,7384	175,1	13,1	7000	86,4	36,8
50	...	...	...	0	0	3,5	8,3	24,1	486	0,7520	143,5	11,9	6540	111,6	49,1
100	...	...	...	0	0	0,7	2,3	10,2	—	0,7859	97,1	9,0	5380	170,2	79,3

a = 50 cc of blend in 100 cc Erlenmeyer flask with 2 mm vent, exposed 15 days in saturated atmosphere for 12 hours at 0° C and 12 hours at 38° C each day.
b = 500 cc of blend in 1 000 cc bottle with 2 mm vent exposed 15 days out of doors.
c = 100 cc of blend in 150 cc beakers at 29° C, exposed for indicated time.

significance since these lead to a more efficient conversion of heat into work[9].

Antiknock Value

The high antiknock value of ethanol has featured prominently as a reason for the pursuit of alcohol fuels. The Research Octane Number (RON) of ethanol blends is determined from the RON of the petrol base, the fraction of ethanol in the blend by volume (x) and the Blending Research Octane Value (BOV) of the ethanol :

RON blend = x BOV ethanol + (1 − x) RON petrol.

The BOV of ethanol varies from about 107 for blending with 98 RON petrol to 160 for a 40 RON petrol base[1]. A good illustration of the octane raising ability of ethanol is shown in Figure 5 which clearly indicates the fall in octane raising ability of ethanol for higher petrol grades[17]. In formulating Gasohol in Nebraska an increase of 5 units on 92 for the RON of unleaded petrol is obtained in a 10 percent blend[19]. The octane raising ability of ethanol is an aspect which could have some potential in optimising the cost structure of petrol blending stock and ethanol.

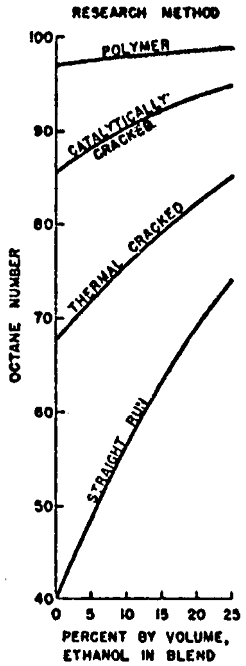

FIGURE 5 Variation of octane rating with per cent of ethyl alcohol in fuel-alcohol blends.

Driveability (Starting, Vapour Lock, etc.)

Ethanol blends up to 20 percent have physical characteristics (Table 5) which are within the range of variation of petrol. Therefore except under extreme conditions which would normally require special petrol formulations no undue behaviour is to be expected for the blends. Reports of cold start problems emanate usually from extremely cold climates and have genenrally less relevance to ethanol than methanol[6]. It has been found that for a 10 percent blend it is possible to start at lower temperatures than with petrol if the atmosphere is above −18°C. The reverse applies at lower temperatures and slight increases in minimum starting temperatures would be expected in the case of 20 percent blends[7]. At the same mixture strength, ethanol blends show the same driveability demerits as petrol[2].

Vapour lock is a problem more likely to occur under subtropical climate and is as much a function of the engine and fuel supply system as the fuel type. In addition the formulation of the petrol blend stock is also of importance. Generally it is reported that the Reid Vapour Pressure of a 10 percent ethanol blend will be higher than that of the petrol but this is not always the case. It has been reported that no vapour lock or starting problems have been experienced in Brazil using blends of up to 20 percent ethanol[20]. Experience with Gasohol gives a similar conclusion for 10 percent blends but it is reported in addition that after numerous measurements on unleaded petrol base stocks and Gasohol there is no evidence of a higher Reid Vapour Pressure for the latter and in fact it is sometimes lower than for the original base stock. Furthermore, after extensive tests driving at temperatures of 38°C and more at altitudes of up to 1 524 metres no vapour lock conditions have ever been experienced[19].

Exhaust Emissions

The use of a 10 percent ethanol blend can reduce carbon monoxide emission by up to 75 percent mainly due to the leaning out effect. Hydro-carbons are also reduced but to a slightly lesser extent as are oxides of nitrogen[2]. Tests by ERDA on Gasohol have confirmed these observations[19] and in addition the use of unleaded petrol-ethanol blends eliminates pollution of the atmosphere by lead which is a serious consideration in the U.S.A.[3]. A reduction in emission has been reported in Sao Paulo of about 20 percent for 20 percent blends.

A recent report on a 1974 Brazilian vehicle has been published by General Motors[11] using petrol of two levels of volatility and blends of 5,10 and 20 percent ethanol. Hydrocarbon and carbon monoxide emissions were reduced in proportion to blend strength to 50 percent of original levels at 20 percent ethanol. Oxides of nitrogen increased insignificantly. Aldehyde emissions doubled at 20 percent ethanol. Aldehyde emission represents about 0,05 g/km against 50 g/km for carbon monoxide and 5 g/km for hydrocarbons. At present aldehydes are not regulated by the U.S. Environmental Protection Agency[13].

Engine Wear

Alcohol blends are known to have a decarbonising effect on engines probably due to the ability to dissolve petrol resin deposits. This also applies to deposits in fuel lines. Occasional problems may be experienced in the initial change to an ethanol blend if dislodged deposits foul fuel filters[9]. The few reports of abnormal engine corrosion by ethanol blends have been traced to corrosive denaturants. Generally less corrosion is experienced with ethanol blends. However, high ethanol content blends could lead to some acetic acid formation, enough to cause corrosion of metals such as aluminium and copper if present in exhaust systems[9]. The 3 million km Gasohol test has confirmed that no unusual engine wear occurs in the use of a 10 percent blend[19]. Bench and road tests in Brazil have also indicated no unusual engine wear while in some instances reduced wear has been experienced[20].

Corrosion problems would appear to be isolated and provided correct materials are used for petrol pump diaphragms and plastic fuel filters then no problems should be experienced in the use of ethanol blends.

Note on Diesel Engines

The high latent heat of evaporation of ethanol makes it unsuitable as a straight fuel for compression ignition engines as does the high flash point. These are characteristics of a low cetane (high octane) rating. Ethanol can be blended with diesel oil with the use of blend stabilisers or may be used in a dual fuel injection system[20]. The use of dual fuel injection systems gives improved diesel efficiency and lower emissions[5].

By dual fuel injection maintaining the park by a pilot injection of diesel it is possible to derive 70 to 80 percent of the diesel engine heat requirement from ethanol[15].

Research at the CSIR which is currently in progress has shown that certain additives stabilise ethanol-diesel blends against separation by extraneous water and preliminary test runs have given promising results at up to 15 percent blends. The cost and availability of the blending agent will cause no problems[16].

Distribution of ethanol fuels

Blending

The distribution of ethanol may be effected either by the petrol producer (as has been the case for SASOL) or by the alcohol producer (as for Union Motor Spirit). The former course has a possible advantage in permitting the oil refiner to formulate the blend base stock to optimise his economy and the physical characteristics of the fuel. This applies particularly to the antiknock vapour pressure and emission characteristics of the final blend. A good working relationship between the ethanol manufacturer and petrol base stock manufacturer is desirable if the greatest advantage of any ethanol blend is to be realised.

Toxicology

An earlier report by a Chicago oil company[10] has suggested that in the use of ethanol blends

> "The death rate would probably go up from accidents caused by intoxicated drivers and a poisoned public, with the adoption of the gasoline tank and garage as a source of alcoholic beverages instead of the roadside tavern where the price would be much higher. If alcohol-gasoline becomes compulsory organised crime might take over the business it established during prohibition and not only would the public suffer from racketeering but it would also be called upon to pay the bill for law enforcement."

In the case of Union Motor Spirit a small amount of benzol provided an adequate denaturant and to the writer's knowledge the blend was never exploited for the above purpose.

In the United States[13] the available evidence suggests that the substitution of alcohols for gasoline offers the following air quality benefits :

- Reduced photochemical oxidant formation.
- Elimination of lead and sulphur emission compounds and,
- Elimination of carcinogenic hydrocarbons currently produced by aromatic fuel compounds.

TABLE 6
Comparative toxicity ratings

	Eye Contact	Inhalation	Skin Penetration	Skin Irritation	Ingestion
Gasoline	(2)	(3)	(3)	(1)	(2)
Methanol	2	2	2	1	1
Ethanol	2	1	1	1	1
Formaldehyde	4	3	4	4	3

1 = mild ( ) = estimated—depends on composition
5 = extreme toxicity

Comparative toxicology ratings for the alcohols[13] and petrol are shown in Table 6. Formaldehyde is included for comparison. Although the Threshold Limit Value* (TLV) for gasoline is generally higher than for methanol (260 mg/m^3), gasoline is much more toxic on inhalation and gasoline which contains aromatics is more carcinogenic. Table 6 shows that denatured ethanol in most aspects is less toxic than petrol. It is reasonable to assume that damage from spills or other acute exposure would be significantly less than for petrol.

The reduction of carcinogenic aromatic compounds in petrol is possible in the formulation of petrol blending stocks for ethanol blends. This could be a further advantage of ethanol blends[13].

Safety

There are no special hazards for ethanol listed by the National Fire Protection Agency of the U.S.A. for either health or reactivity. The fire hazard rating is the same as for gasoline. Extinguishing agents are water, alcohol foam or carbon dioxide/dry chemical[13]. While the flash point is above that for gasoline the flammability limits are wider (3 to 19 percent by volume).

Storage

All ethanol production in South Africa is under excise control and appropriate security is necessary. While no problems of ethanol blend separation have been experienced in Brazil it is necessary in the initial stages of introducing blends into former petrol storage to check for the presence of water deposits in the bottom of tanks. The water holding capacity of blends is shown in Table 5 which also indicates that phase separation is most unlikely to occur as a result of normal atmospheric moisture absorption. Direct contamination must however be controlled.

Economic Aspects

Cost of Ethanol and Petrol

The determination of production costs for ethanol is not within the scope of this paper but it is considered reasonable to assume that alcohol from molasses can be produced at the current petrol price while direct from cane juice a gate price of 33 cents/litre is appropriate. The current petrol price structure from various published sources is shown in Table 7 and by deduction (making allowance for the recent 2 cents/litre increase which has temporarily been absorbed in the reduction of excise duty) the refinery gate petrol price is 17 cents/litre. Against this the ethanol price can vary from the petrol price up to 33 cents/litre depending on whether molasses, high test intermediate products or cane juice is used as the raw material.

TABLE 7
Factory gate price of ethanol blend (33 cents/litre ethanol)

Cost of blend stock petrol at Refinery	% Ethanol in blend			
	5	10	15	20
14	14,95	15,90	16,85	17,80
15	15,90	16,80	17,70	18,60
16	16,85	17,70	18,55	19,40
17	17,80	18,60	19,40	20,20
18	18,75	19,50	20,25	21,00
19	19,70	20,40	21,10	21,80
20	20,65	21,30	21,95	22,60
21	21,60	22,20	22,80	23,40
22	22,55	23,10	23,65	24,20
23	23,50	24,00	24,50	25,00
24	24,45	24,90	25,35	25,80
25	25,40	25,80	26,20	26,60
26	26,35	26,70	27,05	27,40

* TLV — airborne concentration under which workers may be repeatedly exposed without adverse effect.

TABLE 8
Pump price of various petrol grades

		Cents/litre		
Locality	Grade:	87	93	98
Durban		—	35,6	36,3
Reef		38,6	39,3	—
Pongola		—	38,3	39,0
Malelane		—	36,9	37,6
Port Shepstone		—	37,1	37,8
Pietermaritzburg		—	36,6	37,3

Blend Costs

Based on 33 cents/litre for ethanol the blend cost using petrol at various prices is shown in Table 7 for blends of 5,10, 15 and 20 percent.

It has been estimated that the maximum contribution to the petrol plus diesel demand which the sugar industry could make would be short of the equivalent of a 10 percent blend but it is quite possible that augmentation with other crops could double this. However, in the short term it is unlikely that the 10 percent blend would be exceeded significantly. In fact experience with Union Motor Spirit would probably be used as a starting point. It would be appropriate therefore to base initial consideration on the 10 percent blend (equivalent to Gasohol). Table 7 shows that at 17 cents/litre for petrol the blend ingredients would cost 18,6 cents/litre, i.e. only 1,6 cents higher than a litre of petrol. The difference is sufficiently small to warrant consideration of scope for bridging the gap.

Blend Bonus Points for Narrowing the Price Gap

The possible advantages of ethanol blends are :

(i) the high antiknock value of ethanol could lead to cost savings in the formulation of petrol blend stocks and addition of tetraethyl lead;

(ii) decentralisation of ethanol production and blending could reduce blend costs through transport savings at points remote from oil refineries;

(iii) increased efficiencies as indicated in recent tests in Brazil and the U.S.A. leading to more kilometres per litre may justify a higher price for blends;

(iv) reduced emissions may lead to advantages which could reduce air pollution control costs, (e.g. catalytic exhausts) and justify a higher blend price;

(v) the production of renewable fuels to extend fossil fuel supplies could justify relief from the Equalisation Fund levy for such extenders and

(vi) further encouragement may be given in the form of at least partial waving of excise duties as is the case for Gasohol in Nebraska;

(vii) the use of final molasses or higher grade molasses would reduce the cost of raw materials and thus the cost of ethanol.

The above points are discussed in more detail below :

(i) In the case of Gasohol the 10 percent blend increases the RON by 5 units (92 to 97). On this assumption it would be possible to raise regular 93 to the equivalent of 98 premium by adding ethanol up to a 10 percent blend. Bearing in mind that the BOV of ethanol is greater for petrol blend stocks of lower RON, then the 10 percent blend should also bridge the gap between 87 and 93 grades used inland. Table 8 shows that the three grades in question each differ by 0,7 cents/litre. It is possible that liaison with oil refineries may lead to greater savings in blend stock formulation to mutual advantage of the producers of both petrol and denatured ethanol and the consumers. Certainly it could be expected that the formulation of 87 octane blends from a base petrol of say 80 octane (or less) with 10 percent ethanol would lead to greater savings than Table 8 suggests. However, based on Table 9 a saving of 0,7 cents/litre on the 90 percent petrol would reduce the blend price by 0,63 cents/litre and reduce the 1,6 cents/litre excess (see previous subsection) down to 1 cent/litre.

(ii) On the assumption that ethanol production is conducted in small backend distilleries and the denatured ethanol is mixed with transported petrol blend stock then a cost adantage would be possible on the ethanol as shown in Table 8. This applies only to the ethanol constituting 10 percent of the blend and the maximum saving on the blend would be about up to 0,3 cents/litre. This would leave a gap of 0,7 cents/litre.

(iii) and (iv) Although there is much evidence to show that consumption and emission advantages can be expected the savings in practice under local conditions would have to be evaluated before any additional fuel costs could be justified. However, at 36,3 cents/litre a 2% saving would justify a 0,7 cents/litre price increase and this would bridge the gap. For this reason a careful study on 10 percent ethanol blend economy against petrol would be justified as a matter of urgency.

(v) and (vi) There would be no moral justification for applying the Equalisation Fund levy to ethanol which is a renewable extender to finite fossil fuels and this could justify a price saving of up to 0,8 cents/litre on the blend. As this combined with (i) and (ii) above would already bridge the gap further excise relief would not be necessary.

(vii) Should relief from the Equalisation Fund levy not be possible then current prices would restrict the permitted raw material cost and an equivalent of 7 cents/litre would have to come off the raw material (and processing) costs. Details of the methods of achieving this are beyond the scope of this paper but it would be pertinent to point out briefly that at R14 per ton cane the raw material cost is 18,7 cents/litre against about 6 cents/litre for final molasses at R17/ton or 12 cents/litre at R34/ton. The use of final molasses would save 6,7 cents/litre to 12,7 cents/litre in raw material costs and would also save the debit of juice extraction and processing costs on ethanol (being borne by sugar) which would save a further 7 cents/litre. The total saving for final molasses is therefore 13,7 to 19,7 cents/litre depending on whether the local or export price is applied. This results in a 1,4 to 2,0 cents/litre credit to the blend cost gap. Since this at least doubles the outstanding gap to be filled (0,7 cents/litre) it is apparent that the use of ethanol blends from molasses at either local or export price can be economically justified. Furthermore since this would apparently leave a credit in the petrol blend price gap in favour of the blend it is apparent that it would be economically feasible to use blends of 10% produced from enriched molasses.

The above data suggest that for molasses at the export price a mixture of final molasses containing additional sucrose up to the equivalent of doubling the ethanol production from final molasses alone would produce an economical 10 percent blend under present conditions selling at the current petrol price. The economic level of molasses enrichment would depend upon local circumstances and those mills having high molasses transport costs and high petrol costs would be at the greatest advantage for blending and distributing to local outlets.

Insufficient information is available at present to permit an appraisal of the economics of ethanol-diesel oil blends. However, moves to extend diesel with petrol would balance the importance of diesel and petrol supply and demand. In a crisis situation this aspect may fall away.

Conclusions

1. It is evident that all likely contenders to replace present automotive engines will operate efficiently on alcohol fuel blends and it is concluded that in the period during which petroleum demand begins to exceed supply in the 1980's alcohol fuels will assume increased importance as petrol extenders.
2. The physical properties of up to 20 percent ethanol blends do not differ markedly from petrol and favourable experience in Brazil and the U.S.A. in extensive test runs and routine motoring confirms that there are no problems with blends up to 20 percent in standard spark ignition engines. Up to 15 percent ethanol blends with diesel oil also appear not to cause problems provided a blend stabilising agent is added while increased ethanol ratios may be utilised in the dual fuel mode.
3. Ethanol blends have a number of advantages over straight petrol including a higher antiknock value, lower exhaust emissions, higher efficiency and possibly more kilometres per litre.
4. The cost difference between ethanol blends at 10 percent is already sufficiently low to warrant production from molasses. However by making allowance for advantages of the blend it appears possible, depending on local transport advantages, to justify increasing the purity of final molasses to up to the equivalent of doubling the ethanol production from normal final molasses.
5. It is suggested that the present economics are sufficiently interesting to justify a careful evaluation of ethanol advantages under local conditions.
6. Close liaison with oil companies in formulating petrol blending stocks will lead to mutual advantage for the ethanol and petrol producers and the blend consumers.

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For Discussion see page 18

PANEL DISCUSSION — FUEL FROM SUGARCANE

Professor E. T. Woodburn: The Department of Chemical Engineering at the University of Natal has concentrated its research efforts on the production of motor spirit from bagasse, which is considered to be a longer term objective than the direct production of ethanol from sucrose.

I believe that the technology of designing ethanol plants from sucrose is already available and what is needed is not research in this area but in fact a commitment by the sugar industry to at least a provision of funds for the construction of a meaningful pilot plant based on *modern* concepts for the production of industrial alcohol.

With respect to the research on bagasse, it is clear that if bagasse can be utilised to produce motor spirit, then the contribution of the raw material cost has been shown to be the major individual cost factor, as reported by Dr. A. B. Ravnö, then there is a strong motivation for the urgent prosecution of this research.

The research itself can be subdivided into three areas :

1. Development of energy efficient techniques for the preparation of the fibre prior to hydrolysis. (Conservation of Angular Momentum).
2. The development of energy efficient techniques for the concentration of the alcohol from the dilute beer produced by fermentation (Reversible separation).
3. The production of glucose and xylose by hydrolysis of the cellulose and hemicellulosic materials in the fibre.

Progress to date.

The department of Chemical Engineering has run a mixture of one-third rectified spirit, one-third furfuraldehyde and one-third gasoline as a motor fuel for a standard Chevair car now having done at least 14 000 kilometres of essentially cross-town traffic. With only minor modifications this fuel has proved to be eminently suitable as a motor spirit and no discernible mechanical deterioration of the engine parts has been noticed over this period.

The object of the prolonged test has been to demonstrate :

(a) that it is not necessary to dehydrate the ethanol completely before blending it with gasoline.
(b) that it is possible to add a third component which is also derived from bagasse firstly as a mere volume-extender of the fuel but potentially and more importantly as the basis for the production of solvents which would enhance significantly the fuel characteristics of an ethanol/gasoline blend.

In parallel, laboratory and semiscale work concerned with the production of glucose from residual cellulose has proceeded using the fungus *Trichoderma viride* which has now been successfully grown on bagasse. In addition the resulting cellulase broth has now been successfully used to produce glucose from the cellulose fibre.

The major technical difficulty in this area was the sterilisation of the bagasse and techniques have been successfully developed whereby this can be achieved.

Immediate Future Programme.

1. The continuation of investigations into differential acid hydrolysis to produce xylose solutions.
2. Development of optimum enzyme profiles for cellulose hydrolysis.
3. It is the immediate intention of the Department to build a general purpose hydrogenation reactor whereby the furfuraldehyde can be converted into hydrogenated derivatives which will enable aqueous alcohol mixtures to be blended successfully both with gasoline and dieseline. The modification of the properties of the complex solution by preparing various chemical derivatives of the furfuraldehyde is an interesting possibility and by doing this we should certainly be able to change the total vapour pressure curve thus facilitating cold starts and possibly by adding side chains and additional rings to the solvent we could significantly improve the combustion charateristics of the combined fuel in both spark ignition and diesel engines.

Finally, I might say that I regard this work as being of major technical importance to the country and also of very significant socio-economic value. It seems to me that the sugar industry ought to participate in this programme as vigorously as it possibly can, starting now.

Mr. S. W. A. C. Matthews: Much publicity has been given to views that someone should get on and make ethanol for use in motor fuel but so far no rules seem to have been spelt out. It is common cause that something has to be done — from a national viewpoint.

For a company to be able to decide it is necessary to know on what basis to forecast revenue, i.e. what will be deducted from the bowser price — especially by way of levy or duty.

An article in a Cape newspaper last week had it that Sasol II viability was based on 12 or 13 cents per litre. We have the anomaly that SASOL is extracting alcohol from its motor spirit stream for sale in the alcohol market while all the talk goes on about producing alcohol to blend with petrol or dieseline.

Ethanol production technology is not a problem nor is its use.

From what has been said earlier today it seems disposal of effluent on the lands is a possibility.

The necessity must again be stressed for having rules spelt out so that economics can be studied.

D. J. L. Hulett: In 1978 50% of the vinhasse (distillery slops) in the state of São Paulo was disposed of in the rivers — this year, 1979, not one drop of distillery effluent goes to the rivers.

No mill was allowed to start up unless it had an approved system of effluent disposal together with a 28 day safety area where the effluent could be disposed of should the main system fail.

Various methods are being used to dispose of this effluent and in my opinion the best one is to dispose of it through the irrigation system. One factory, Usina da Pedra, for instance dilutes the vinhasse 4 : 1 with water, adds in all the filter mud and a little lime, and pumps this mixture to the top of a hill from where it is used to furrow irrigate a large area of cane. The amount of irrigation is contolled by the potassium level of the soils as this salt is the predominant mineral contaminant in the effluent. Nitrogen is added to the field at a later date by airplane if this appears necessary from the condition of the cane.

A second method to distribute the vinhasse to the field, where an irrigation system is not available is to haul the liquid away in 8 ton road tankers and apply it to the fields as a spray directly from the tankers. This system is expensive and various evaporator schemes are being developed to concentrate the vinhasse removing 80% or more of the water. Most of these evaporators will make use of the steam going to the distillery and the hot vapours being condensed in the distillery to achieve this concentration without the use of any additional steam.

At present all motor fuel (gasoline) in Brazil contains 20% alcohol and the intention is to produce enough alcohol to supply 100% of the country's liquid fuel needs. Already various centres have alcohol pumps which supply 96° alcohol which cannot be mixed with petrol. Conversion kits are available for V.W. engines and Fiat is marketing an alcohol engined car. Alcohol at the pump is two thirds the price of petrol. Various fleets of vehicles such as the Post Office fleet in the City of São Paulo are completely powered by alcohol.

In the diesel field work is being done on dual fuel engines (there is a Sconia truck running on a dual fuel conversion in Porecatu) and also on alcohol + additive replacement fuel.

Usina São Jouo has a GM Diesel truck running on a mixture of alcohol + 15% castor oil.

However, no general solution to the diesel problem is available at the moment and this little problem has been left to solve the easier ones first. In the meantime surplus "gasoline" is being exported to neighbouring countries.

Mr. J. B. Alexander: In Brazil, the Miller receives the same price for making alcohol as he would receive for making sugar.

Mr. J. L. du Toit: The world at present is living on capital with regard to its use of fuel. Oil will maybe last for fifty years, coal for a hundred years or so, and there is only a limited amount of concentrated uranium available. The use of nuclear power could cause catastrophic problems.

We must therefore turn to the sun for energy. It must be economic to use sugarcane for alcohol, particularly in times of surplus, as at present. Are we quite sure that we will always be able to export sugar?

The energy problem is a national problem and some firm decisions must be taken now as to how the matter will be tackled.

The SASOL plants are extremely necessary but vulnerable whereas alcohol distilleries can be spread, for example, by having them on the South Coast, the North Coast and Zululand.

The Sugar Association should present its case to the government and press for a firm decision. Although an objection has been raised to producing fuel from food, if such food is being exported at a loss then the argument falls away.

Mr. O. d'Hotman de Villiers: I have little to say after what Mr. du Toit has just said. The US has enormously increased cane production per hectare in Hawaii by correct use of fertilizer. In Texas, with a 12 month crop and 4 ratoons, average production is 90 tons cane per hectare, but a few growers average 180 tons. It is estimated that the *average* yield in 12 to 20 years' time will be 134 tons per hectare (*Hipp*) as compared with the 90 tons average at present. In Mauritius a cross between wild Marot cane and POJ28 has produced a vigorous low purity Ethacane which is very suitable for alcohol production.

Tate & Lyle has made a significant contribution to the spillage disposal problem by using continuous fermentation.

The cost of alcohol is quoted at 24 – 34 cents per litre in Australia but if the full value of by-products is taken into account this figure, it has been stated, can be reduced to about 21 cents.

Professor P. Meiring: The diesel/petrol ratio is our very short term problem. Because 25% of our diesel is used in agricultural practice these tractors must be maintained in service.

Adding ethanol to diesel could improve the diesel/petrol ratio because less diesel would be used.

However, if the diesel that will be supplied by the companies has a changed specification, e.g. allowing more of the lighter fractions in the diesel, we might have difficulty in the amount of ethanol that can still be added to this diesel.

Furfurol could perhaps play a role as its derivatives help as a mixing agent and it is itself a fuel. However, furfurol production at this stage is still too expensive.

The mixing problems could be overcome by modifying tractor engines, e.g. by means of twin fuel systems, but the total cost of such a conversion for 300 000 tractors would be prohibitive at this stage.

A word of warning — before ethanol is introduced time will still be required for research.

I believe that we need a policy statement as to what quality diesel will be supplied and whether the production and use of ethanol from agricultural crops will be encouraged by the authorities.

Mr. P. V. van Breda: I was recently at an alcohol symposium in the United States which was attended by 500 delegates from about 15 countries and where 70 papers were presented.

A country's prosperity and standard of living is closely related to energy availability and dependence on outside sources for energy requirements should therefore be minimal.

It takes so long to apply new technology that it is essential that a decision on ethanol be taken now.

Canada has plentiful supplies of oil and gas and yet is spending large sums researching energy from forests and other renewable energy sources.

Cost of production is not the only factor to consider. Availability is also important, as is the fact that in the case of locally produced alcohol money is spent inside the country.

In South Africa land and sunshine are plentiful and urgent attention should be given to increased production of agricultural crops and forestry for energy in regions where rainfall or water supply permits. The Forestry Council has recently provided a grant for a feasibility study of fuel from timber. It is time for agriculturalists to be regarded as industrialists, using sun, soil and water to produce energy and the price they receive for their products should be placed at a level which makes production attractive and bears this important aspect in mind.

The introduction of fuel alcohol must be a combined effort on the part of Government, oil companies, car manufacturers and public. The sugar industry should examine the extent to which present surplus cane and molasses and potential cane can be harnessed for the manufacture of alcohol and ask the Government to assist in formulating an overall energy plan including alcohol so that the industry can invest and operate profitably.

South Africa should take a lead from Brazil on the alcohol front — less talk and more action.

Dr. R. E. Robinson: Let me first say how delighted I am to be standing up before an audience of people who are obviously complete alcoholics. This is a most pleasant change from previous situations of even a year ago when there were very few people indeed who were converted to the concept of making alcohol out of agricultural materials, least of all, sugar-cane. It is very pleasant to obtain the impression that at least 99% of this audience today are completely converted to the concept that we must produce ethanol from our agricultural materials in this country and that sugar-cane is potentially one of the most important sources.

In this regard I would like to take issue with one of the previous speakers who placed a lot of emphasis on the so-called NER (Nett Energy Ratio) as being one of the most important criteria for selecting the particular agricultural product from which ethanol can be made. I certainly accept that this is an important concept in many parts of the world where they have no significant energy resources at all. However, in South Africa where we have abundant supplies of coal, where our reserves have been estimated at 60 000 million tons, with an annual consumption of the order of 100 million tons per annum, it is quite clear that we have enough coal supplies to last us for a long time. Under these conditions and provided that we use coal as our main energy source for evaporating the solutions necessary in ethanol production, I do not believe that the nett energy ratio or the overall thermodynamic balance is an important criterion. After all, if we look at our mammoth Sasol undertakings, without any doubt, these have a very small nett energy ratio — well below any figures that have been quoted here today for ethanol production. In fact, one can extend this further to any electric power station and any of the many other activities that we undertake in this country to generate useful forms of power or energy from coal. Thus I believe that, in assessing the viability of alcohol production from various agricultural products, we can ignore the NER parameter.

Of far greater importance to me is the total availability of material and it is surprising how difficult it is to get hard factual informaton. For example, I have asked many people to provide an estimate of what the total sugar-cane production potential is in South Africa and I have received many different opinions from experienced and informed people, ranging from a statement to the effect that we could easily double our sugar-cane production, to other estimates that maybe 20% increase of existing levels is perhaps all that we can anticipate. Clearly one of the reasons for this is the uncertainty regarding the availability of water for irrigation and I accept that this is a difficult task, nevertheless, the long-term supply potential of any agricultural material is an important consideratoin. If industry is going to spend large amounts of capital establishing plants to produce fuel, it must be assured of its raw materials supply.

The third point I would like to make in my presentation and which I believe will be of particular interest to the technically oriented audience here today, is the importance of maintaining efforts at a high level of research, and in this regard I believe you will be interested to learn of some of the new research directions that we in the Sentrachem organization are taking. Of particular importance is our attempt to utilize all by-products arising from an ethanol production programme by fermentation and one of the by-products that has been sadly neglected in the past is the carbon dioxide which is an inevitable product from any fermentation reaction. Sentrachem, in collaboration with Professor Toerien at the University of the Orange Free State has now established a research group which is going to look at the utilization of this carbon dioxide for the cultivation of algae. You probably all know that algae are a form of living material that is a very efficient converter of carbon dioxide into a number of different useful materials such as carbohydrates, sugars and proteins. Some indications in the literature reveal that it should be possible, with the help of sunlight and photosynthesis, to cultivate algae at a rate which could amount to well over 100 tons per hectare per annum. I would remind you that typical rates in the case of maize are 3 tons per hectare per annum, and in the case of sugar, approximately 10 tons, and with some of the other crops, like the SAVA people claim, 30 to 40 tons per hectare per annum. However, it is quite clear that if one can cultivate algae in a suitable system, the utilization of land area and sunlight could be very much higher than in the mere cultivation of agricultural crops. It is hoped that the algae themselves can either form the base for further fermentation reactions or will form a product which can be incorporated in animal feeds and providing proteins for their food value. Indeed, it would appear that many of the algae are efficient producers of proteins which contain lycine in high quantities. This material will form a perfect balance to some of the other forms of protein material that are available and it could well provide the answer to the major Kwashiokor that exists in South Africa — indeed in Africa as a whole.

We believe that this line of research work will not only produce additional valuable products to an ethanol programme but will also in effect solve all effluent treatment problems since any effluent from the plant can now easily be diverted into these algae ponds and converted into useful products.

I mention this approach by Sentrachem and the University of the Orange Free State because we welcome any collaboration that may be forthcoming from other scientists in South Africa.