CHEMICAL ECONOMICS - BIOFUELS

In this paper I will discuss some aspects of the economics of fuels and chemicals production from renewable resources which are often touted as leading to a carbon free economy. As a basis for the discussion I will use as an illustration the production of ethanol and the conversion of ethanol into ethylene.

Chemistry

Ethanol is produced by a wide variety of fermentation processes of which the most widespread is the conversion of sugar (such as sucrose) or starch into ethanol and carbon dioxide. The reaction stoichiometry is:

$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_5OH + 4CO_2$$

This is the most widespread route as it is the basis for the production of potable ethanol (booze) and in most jurisdictions attracts large excise taxes (currently $80/L for whisky). It is also used in the production of ethanol fuels in the US and Brazil and at Sarina (sugar molasses) and Dalby (sorghum) in Queensland. Note however that most Australian fuel ethanol is produced as a by-product from starch manufacture at Manildra in NSW and this process is not considered here.

One point to note is that a typical fermentation takes place in a relatively dilute solution so that one of the main operating costs is the separation of the ethanol from the excess water.

Ethanol can be dehydrated to produce ethylene at temperatures usually over 200^{o}C (500K):

$$C_2H_5OH = C_2H_4 + H_2O$$

This is an equilibrium reaction (Figure 1) with a large portion of industrial grade ethanol being produced by hydration of ethylene at low temperatures.

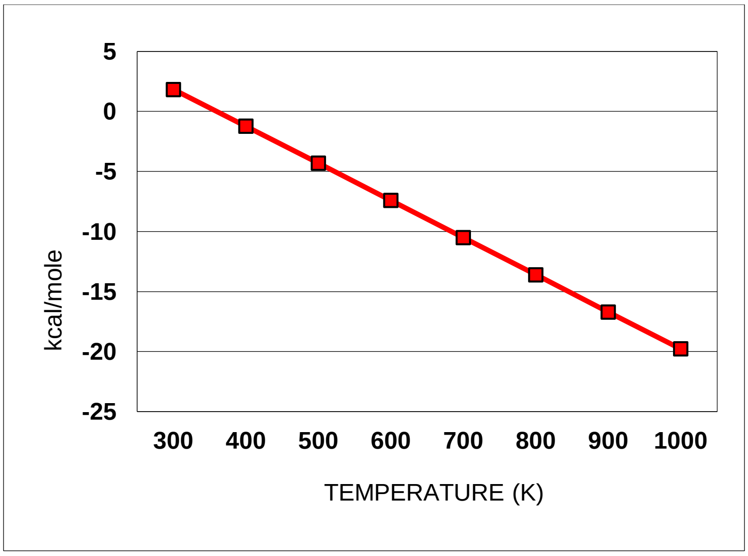

Figure 1: Free energy change C2H5OH = C2H4 + H2O

High potable excise results in heavy regulation of industrial ethanol which is generally tax free and fuel ethanol which is generally taxed at fuel levels ($0.389/L) to ensure the integrity of the fuel excise system.

Prior to the advent of the petrochemical industry ethylene was often produced by dehydration of ethanol and is still found in small facilities in some countries (India, China) and was once used in Australia by CSR Chemicals at Rhodes. Recent interest in renewable plastics has reinvigorated work in the process.

Process Economics

Ethanol

Table 1 gives illustrative economics using sucrose (as Molasses) as the feedstock. The first two columns give scenarios for two typical scales of operation - capital and operating costs are in 2013 US dollars. Sugar for this example was priced at $300/t.

		ETHANOL	ETHANOL	ETHANOL
FEEDSTOCK		molasses	mol + sugar	lignin
ETHANOL OUTPUT	ML/y	56.79	37.86	56.79
CAPITAL COST	$Million	49.63	37.10	65.91
CAPITAL COSTS	c/L	11.86	13.30	15.75
OPERATING COSTS	c/L	27.35	29.09	35.70
FEEDSTOCK COSTS	c/L	51.78	51.78	4.89
ETHANOL PRODUCTION COSTS	c/L	90.99	94.17	56.34
gasoline at current oil price)	c/L	43.73		
CAPITAL COSTS	$/t	150.31	168.55	199.60
OPERATING	$/t	346.67	368.75	452.47
FEEDSTOCK	$/t	656.26	656.26	61.98
TOTAL	$/t	1153.24	1193.56	714.05
gasoline ($/bb at current oil price)	$/t			594.71

The data illustrates that ethanol production cost is over 90c/L, which is more than double the cost of gasoline (petrol) at the current oil price of about $65/bbl (Tapis crude). On an energy equivalent basis ethanol would have to be priced at 30c/L. This difference in cost is made up, depending on the jurisdiction, by tax breaks, capital subsidies or mandates on use.

Furthermore the cost of feedstock is higher than its value as gasoline. Because of this and the impact on the use of sugar and similar foodstuffs for ethanol forcing increased food prices, there is much effort in developing non food feedstock such a ligno-cellulose (wood fibres). There is a paucity of information on the cost of this process but in the last column of Table 1< I have placed some indicative costs for a similar output. There are three points:

1. Capital costs is higher due to a more complex process and the handling of large volumes of primary feedstock which will require additional processes such as drying and shredding. There is also the need for specialist enzymes for the process which will be produced on-site in a separate facility.

2. Operating costs are higher reflecting a more complex process which will include the disposal of significant volumes of waste material

3. Feedstock cost is not zero, as might be assumed. Proposed sources will require collection (whether forest waste, corn stova or bagasse etc.) and transported (by truck) to the facility. The transport cost in energy terms limits the scale of the operation to a relatively small facility so that economy of scale is limited. The notionally free feedstock may have a value (such as mulch) which will have to be recompensed in some way.

Assuming a value of $20/t for the cost of the feedstock and a 65% efficiency in the process then production costs are reduced to 56c/L which is still higher than the cost of gasoline at current oil prices. Without on-going subsidy, this revolutionary new route only makes sense at significantly higher oil prices.

The sensitivity of the cost of production is shown in Figure 2.

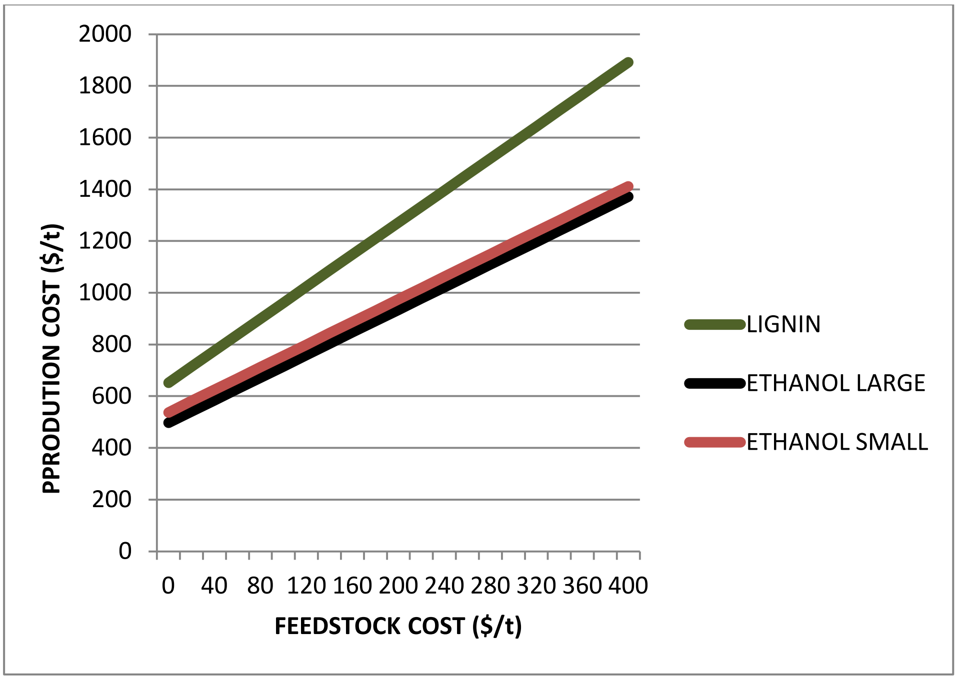

Figure 2: Ethanol production cost versus feedstock price.

Ethylene

Rather than use ethanol for a relatively low value commodity such as fuel, what about conversion to higher value ethylene? The bottom rows in Table 1 express the costs in terms of $/t to help evaluate this proposal. Table 2 gives the salient statistics using ethanol priced on an energy equivalent basis to gasoline (29c/L):

	Mt/a	PJ/a	$M/a
CAPITAL COST (US$)			$50.00
OPERATING COSTS (10% CAPEX)			$5.00
RETURN ON WC (10%)			$5.73
RECOVERY (10%DCF, 20y, FACTOR 0.143)			$7.15
FEEDSTOCK & FUEL PURCHASES			
Feedstock	0.900	26.86	$332.02
Operating Feed (5.5%)	0.050	1.48	$18.26
Fuel (for power)	0.022	0.95	$7.87
Operating Fuel (3%)	0.001	0.03	$0.24

TOTAL	0.972	29.32	358.39
OUTPUTS			
Ethylene	0.500	25.15	
TOTAL	0.500	25.15	$0.00
THERMAL EFFICIENCY (%)		85.78%	
ANNUAL COSTS			$376.27
UNIT ETHYLENE PRODUCTION COST ($/t)			**$752.54**

The sensitivity of the production cost is shown in Figure 3.

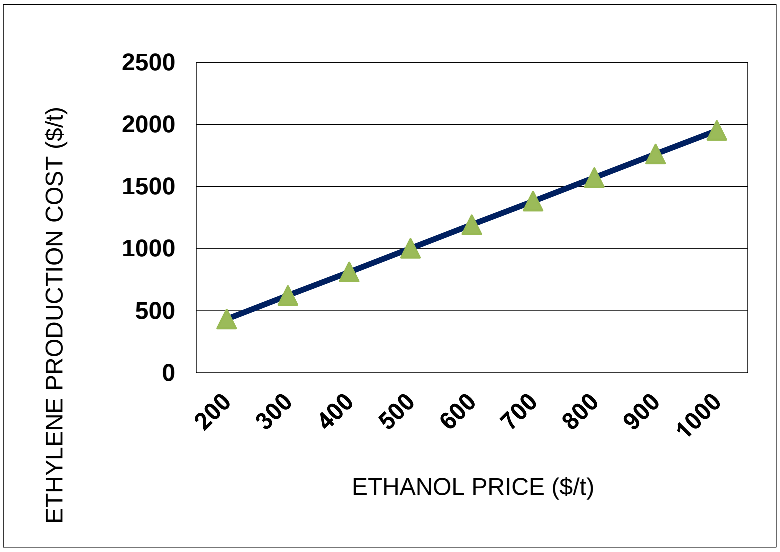

Figure 3. Sensitivity of ethanol production cost with ethanol price

With a typical ethylene value of about $1300/t, ethanol prices have to be below about $600/t to make this route viable. As noted from Figure 2, this is only likely to be achieved by new (unproven) routes using low cost ligno-cellusosic feedstock with cost below $40/t.

Conclusions

Although there is much interest and political will to develop and promote ethanol as a renewable fuel, this economic analysis shows that the current technology is only viable at high oil prices (>$100/bbl) with some form of government subsidy. At current oil and sugar prices the level of subsidy is very high and would present a major hurdle for private investment in this sector.

This study also shows that new routes using ligno-cellulose as a feedstock would require high oil prices to succeed. At present the technology is marginally viable at best and still requiring a subsidy at the current oil price.

Converting ethanol to ethylene (a higher valued option) shows also poor viability unless the ethanol was available at energy equivalent prices when the production cost would be similar to the product of ethylene from ethane by steam cracking (see Chem Aust previous article).