M17 - THE POTENTIAL FOR ETHANOL PRODUCTION FROM SUGARCANE IN AUSTRALIA

By

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Abstract

The Australian sugar industry processes approximately 35 million tonnes of sugarcane per year from 400 000 hectares of land. Sugar remains the principal revenue stream from sugarcane in Australia with less than 60 ML/y of fuel ethanol produced from final molasses at present. Modelling has been undertaken to estimate the potential ethanol production from the Australian sugar industry for integrated facilities producing both sugar and ethanol from the entire sugarcane resource. Although research aimed at developing commercial processes is ongoing, the use of a proportion of the bagasse and trash for ethanol production, in addition to juice and molasses fermentation, would allow significant increases in the scale of ethanol production from sugarcane in Australia, increasing total industry revenues while maintaining energy self sufficiency.

Introduction

Although some of the earliest combustion powered transportation vehicles were fuelled with ethanol, crude oil derivatives have provided the vast majority of transportation fuels throughout the 20th and early 21st centuries. This overwhelming reliance on crude oil as the source of virtually all transportation fuels has been the result of abundant supplies of crude oil in vast deposits that have been inexpensive to extract, refine and distribute to the consumer. The high energy density of the major crude oil derivatives (automotive gasoline, diesel and aviation fuels) has enhanced the suitability of these fossil fuels for transportation fuel use.

In 2006, global demand for liquid fuels and other petroleum products was 85.0 million barrels oil equivalent per day (Mb/d) and this is forecast to grow to 106.6 Mb/d in 2030, with the growth in transportation fuel use being responsible for around 80% of the increase (EIA, 2009). Despite the dampened demand resulting from the global economic recession experienced in 2008-09, world oil prices are forecast to be above $100 /barrel (in 2007 terms) from 2013 onwards. Also, despite improvements in energy efficiency standards in many countries for combustion engines, global crude oil consumption continues to increase by over 1% annually, driven primarily by the increased demand for fuel in developing countries (EIA, 2009), and particularly by the growth in demand in India and China (IEA, 2007).

The only non-fossil liquid transport fuels currently of significance on a global scale are biofuels, including bioethanol and biodiesel. World production of biofuels exceeded 0.7 Mb/d in 2007, an increase of 35% from 2006 and accounting for 1.5% of total road transport fuel use (IEA, 2009). Biofuels production is forecast to grow by about 8.6% annually to approximately 5.9 Mb/d in 2030, increasing to 5.5% of total liquid fuel consumption (EIA, 2009).

Transport fuel use in Australia

Transport fuel consumption in Australia is dominated by the four key fuels – automotive gasoline, diesel, aviation fuel and LPG. Statistics on transport fuel consumption in Australia and in the individual states are reported annually by the Australian Bureau of Agricultural Resource Economics (ABARE) in the series entitled Consumption of Petroleum Products (ABARE, 2009a). The most recent ABARE data on petroleum product use in Australia and the key sugarcane growing states of Queensland and NSW are shown in Table 1.

Table 1 – Consumption of petroleum products in Australia, Queensland and NSW 2007-08 (ABARE, 2009a)

	Australia (ML)	Queensland (ML)	NSW (ML)
Automotive gasoline	19 234	4475	6072
Diesel	18 256	5164	3776
Aviation fuel	6158	1313	2738
LPG	4024	613	1139
Other	3116	573	913
TOTAL	50 788	12 138	14 638

The major growth in transport fuel use in Australia is in the consumption of diesel and to a lesser extent aviation fuels. Over the past 10 years in Australia, diesel fuel use has increased by 42% and aviation fuel use has increased 26% while automotive gasoline use has only increased by 6%.

The capacity of the Australian sugarcane industry

The Australian sugarcane industry extends across 2200 km of coastal Queensland and NSW. Over the past decade, the industry has contracted as a result of a sustained period of poor world sugar prices, drought, disease and industry rationalisation. The Australian sugarcane crop has dropped from a peak of 39.5 Mt in 1998 to 30.3 Mt in the 2008 season. Area harvested has decreased from a peak of 450 000 ha to about 370 000 ha (ABARE, 2009b). The average Australian sugarcane productivity over the previous ten year period was 85.8 t/ha, varying on a seasonal basis between 69.8 t/ha and 99.1 t/ha. With the reduction in milling capacity in some areas, a proportion of the area lost to sugarcane cultivation is unlikely to be readily returned to production. Higher world sugar prices in 2008 and 2009 are likely to result in the stabilisation of sugarcane production and perhaps some increases in sugarcane cultivation in several areas in the short term.

It seems likely that, unless there is a sustained step change in the world sugar price or a significant move to high biomass sugarcane cultivation, sugarcane production in Australia in the short to medium term will continue to average between 30 and 35 Mt from approximately 400,000 ha. It is recognised that, in the right business environment, further significant expansion of the sugarcane industry in Australia is possible particularly through tropical Queensland, Western Australia and the Northern Territory, however significant infrastructure and investment capital is required to support this expansion and as a result this possible future expansion scenario has not been assessed in this study.

Ethanol production from sugarcane juice and molasses

Ethanol can be produced from a variety of sugarcane feedstocks, including juice, molasses and crystal sugar. The conversion of sucrose to reducing sugars and ethanol through yeast fermentation of juice and molasses has been previously reported and a good summary is available in Lavarack (2003).

In the fermentation of sugarcane juice or molasses, sucrose is hydrolysed to hexoses (glucose and fructose) which are fermented to ethanol as shown in Equations 1 and 2.

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow 2C_6H_{12}O_6 \qquad \text{(Equation 1)}$$

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 \qquad \text{(Equation 2)}$$

As reported (Lavarack, 2003), the production of significant quantities of carbon dioxide as a by-product of the fermentation process limits the maximum theoretical fermentation yield of ethanol from hexose to 51.14% (w/w) but the maximum practical yield using conventional fermentation organisms is around 48.40% (w/w) as a result of hexose consumption in side reactions.

The maximum theoretical yield of ethanol from sucrose is 105.3% of the ethanol yield from an equivalent weight of glucose, as a result of a mass increase in the initial sucrose hydrolysis reaction.

Approximate ethanol yields per tonne of product are shown in Table 2.

Table 2 – Approximate ethanol yields per tonne of product

	Typical sucrose concentration[1] (%)	Typical reducing sugars concentration[1] (%)	Approximate ethanol yield[2] (L / t)
Final molasses	35.0	13.0	280
B molasses	46.5	8.7	324
A molasses	53.5	5.2	345
ESJ	13.5	0.4	82
Raw sugar	98.9	0.3	590

[1]SRI data

[2]Based on fermentation yield of 88.0%, distillation efficiency of 99.0% and ethanol density of 0.789 kg/L

Ethanol production from bagasse and sugarcane trash

The production of ethanol from the fibre component of tops and leaf (trash) and bagasse is significantly more complex than the production of ethanol from sugarcane juice or molasses as a result of the resilience of the carbohydrates in the fibre to undergo hydrolysis to their monomer sugars. Pretreatment of the fibre through physical or chemical processing is required to make the carbohydrates in the fibre more susceptible to hydrolysis. Hydrolysis is achieved through the application of hydrolytic enzymes or acids.

In general, the hydrolysis reactions can be described as shown in Equation 3 for cellulose and in Equation 4 for hemicellulose (Wyman *et al*., 2005). The hydrolysis of cellulose results in the production of the glucose monomer and from sugarcane bagasse the primary monomers from hemicellulose hydrolysis are the pentoses (five-carbon sugars) xylose and arabinose.

$$(C_6H_{10}O_5)_n + nH_2O \longrightarrow nC_6H_{12}O_6 \qquad \text{(Equation 3)}$$

$$(C_5H_8O_4)_n + nH_2O \longrightarrow nC_5H_{10}O_5 \qquad \text{(Equation 4)}$$

In the cellulose hydrolysis reaction, the molecular weight of the carbohydrates increases by 11.1%, and for hemicelluloses the molecular weight increases by 13.6%.

Due to the harsh nature of the leading pretreatment processes, a number of degradation products may be formed which not only reduce hexose and pentose yields but can be inhibitory to the organisms involved in fermentation of the sugars to ethanol. These degradation products include furfural, 5-hydroxymethylfurfural, levulinic acid, formic acid and acetic acid. Minimising the formation of these degradation products is a critical challenge for any biomass pretreatment strategy.

The crystalline nature of the cellulose in plant fibres typically restricts the economically achievable glucose yield from cellulose hydrolysis, although the glucose released can be readily fermented at very high efficiencies using conventional fermentation organisms.

While hemicellulose can be readily hydrolysed to pentoses using mild acid processes, the slow rate of fermentation of pentoses by yeasts and other organisms restricts the economically achievable ethanol yield from pentoses. A large global research effort is focussing on increasing the economic yield of ethanol from cellulose and hemicellulose by improving enzyme and fermentation organism effectiveness. Currently however, pentose fermentation remains a key challenge for the development of a commercial cellulosic ethanol industry.

When estimating the potential yield of ethanol from bagasse, it is necessary to account for the efficiency of the whole production process. The overall yield of ethanol will be a product of the yields from each of the pretreatment, hydrolysis, fermentation and distillation stages and will account for the different yields from the cellulose and hemicellulose components of the biomass.

For an ethanol conversion efficiency of approximately 80% from cellulose and a moderate 50% from hemicellulose, an ethanol product yield of around 340 L/t dry fibre can be achieved. This consists of about 260 L /t dry fibre from the cellulose component and 80 L /t dry fibre from the hemicellulose component of the fibre.

In most sugarcane factories, bagasse is the primary energy source, where it is combusted to produce steam and electricity for the process and export. Historically, the bagasse has been burnt inefficiently in low pressure boilers and with energy inefficient sugar processing techniques to ensure complete disposal of the bagasse. With increasing prices for sales of export electricity to the electricity distribution network, and for green incentives such as renewable energy certificates generated under the Mandatory Renewable Energy Target (MRET) scheme, there is now a significant focus on energy efficiency improvements of sugarcane factories to maximise electricity generation and export.

In an integrated crystal sugar factory and bagasse ethanol facility, it is envisaged that the energy requirements for the process will still principally derive from bagasse combustion, and it is only the surplus bagasse (the bagasse in excess of that required for process energy) that is made available for cellulosic ethanol production. This bagasse can be supplemented with a portion of the available trash to provide extra fibre for both combustion and ethanol production, while still ensuring sufficient trash remains in the field for its mulch and soil conditioning value. The availability of trash for value-adding applications in a region will depend upon both the economics of trash collection and transport, and the value of the trash to the farming system. A previous biomass availability model has assessed utilisation options based upon additional trash availability of 12.3% for whole of crop harvesting compared to a typical cane supply (SRDC, 2006). The scenarios following assume a maximum trash availability equivalent to 10% of the existing cane supply.

Scenario analysis

A comprehensive technical and economic model of an integrated sugar factory, juice and molasses distillery and cellulosic ethanol facility has been developed at QUT (shown schematically in Figure 1). This model enables the evaluation of possible scenarios for integrated sugar and ethanol production facilities, including integrated options for energy generation and export.

Simulations have been undertaken for several whole-of-industry scenarios to estimate the potential for ethanol production from the Australian sugar industry and the results of five of these scenarios are summarised in this report.

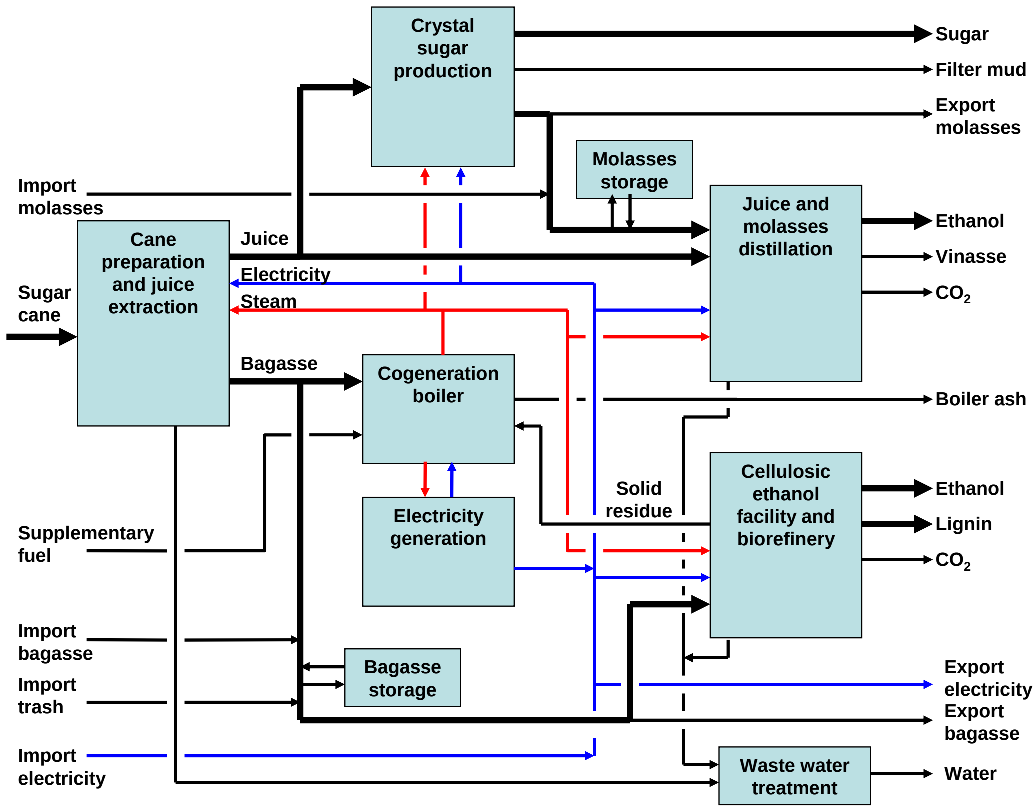

Figure 1 – Schematic representation of the QUT techno-economic model of an integrated sugar factory, juice and molasses distillery and cellulosic ethanol production facility

In all of the scenarios reported, the average Australian sugarcane crop is assumed to be 35 million tonnes. Additionally, it is assumed that a portion of the trash from the field is collected and transported to the factory for processing. The sugarcane processing period is assumed to be 23 weeks / year with the ethanol facilities operating 48 weeks / year, requiring significant bagasse and molasses storage. The bagasse is assumed to be composed of 45% cellulose, 22% hemicellulose and 19% lignin, the remainder being minor amounts of ash, extractives and protein.

Although the model allows for their inclusion, in these scenarios, no value has been included for renewable energy certificates, carbon credits or ethanol production incentives. The analysis excludes rum production at the Bundaberg distillery and other minor ethanol production in small distilleries. It is noted that there is a considerable market for molasses as an animal feed which is likely to limit the availability of molasses for ethanol production, but this is not considered in these scenarios. Likewise, other markets for bagasse or trash products are not assessed.

The five scenarios presented in this paper are:

Base scenario

This scenario models the approximate sugar, ethanol and electricity production in the Australian sugar industry using currently installed infrastructure. In this scenario, no sugarcane juice is utilised for ethanol production and a total of 60 ML of ethanol is produced from final molasses. All of the bagasse is used for cogeneration and the production of export electricity. Bagasse is assumed to be combusted in low pressure inefficient boilers and no bagasse is used for cellulosic ethanol production. No trash is processed in this scenario.

Cogeneration scenario

In this scenario, no sugarcane juice is utilised for ethanol production. A total of 60 ML of ethanol is produced from final molasses. All of the bagasse and a proportion of the available trash are used for cogeneration and the production of export electricity. Bagasse is assumed to be combusted in high pressure efficient boilers and energy efficient process technologies are implemented to maximise electricity generation and export.

Low ethanol scenario

In the low ethanol scenario, no sugarcane juice is utilised for ethanol production. Ethanol is produced from all of the final molasses generated from the sugar production process. Bagasse and trash surplus to the energy requirements of the process are used for cellulosic ethanol production. Bagasse and trash used for energy production are combusted in high pressure efficient boilers and energy efficient production process technologies are implemented.

Moderate ethanol scenario

In the moderate ethanol scenario, 70% of the sugarcane juice is utilised for crystal sugar production with the remaining sugarcane juice utilised for ethanol production. All of the A molasses from the crystal sugar production process is utilised for ethanol production. Bagasse and trash surplus to the energy requirements of the process are used for cellulosic ethanol production. Bagasse and trash used for energy production are combusted in high pressure efficient boilers and energy efficient production process technologies are implemented.

High ethanol scenario

In the high ethanol scenario, no crystal sugar is produced and all of the sugarcane juice is used for ethanol production. Bagasse and trash surplus to the energy requirements of the process are used for cellulosic ethanol production. Bagasse and trash used for energy production are combusted in high pressure efficient boilers.

Key input data for the scenario analyses are shown in Tables 3 and 4 and the results are shown in Table 5.

Discussion

Based on the assumption used, the scenario analysis detailed in this report shows that in a high ethanol scenario, a maximum of 4657 ML of ethanol is able to be produced which equates to 24% of Australia's automotive gasoline requirement or 104% of Queensland's automotive gasoline requirement on a volumetric basis. With the quantity of existing crystal sugar production infrastructure in Australia however, it is very unlikely at any stage in the future that this quantity of sugarcane juice will be diverted from crystal sugar manufacture to ethanol production.

The moderate scenario is a more achievable long-term ethanol production estimate from sugarcane in Australia that may be possible in the right commercial and policy environment. In this scenario, 30% of the current sugarcane juice is diverted from crystal sugar production to ethanol production and, with the production of cellulosic ethanol from surplus bagasse and trash results in the production of 2622 ML of ethanol, equivalent to 14% of Australia's (or 61% of Queensland's) automotive gasoline requirement on a volumetric basis.

It must be noted however, that several significant economic and technical challenges need to be overcome particularly with respect to aspects of the cellulosic ethanol production process and the collection, transport and processing of sugarcane trash before ethanol production at these levels could be realised.

Even in the low ethanol production scenario, over 28% of Queensland's automotive gasoline requirement can be met using ethanol produced from sugarcane resources alone. In all of the scenarios analysed, the process is energy self-sufficient, requiring no significant quantity of coal or other ancillary fuels for energy generation and no significant electricity import during operation.

The proportion of fibre required for energy generation decreases with a decrease in the amount of crystal sugar produced, as a result of the lower energy requirements for ethanol production, increasing the amount of fibre available for cellulosic ethanol production. An increase in the production of export electricity is expected even in the high ethanol production scenario as excess high pressure steam is utilised for electricity generation.

Table 3 – Common input data for scenario analysis

	Common input data
Cane crushed (t)	35 000 000
Crushing season length (weeks / year)	23
Ethanol production period (weeks / year)	48
CCS	13.72
Cane purity	85.9
Fibre % cane	14.70
Fibre % trash	51.06
Cellulose % dry fibre	45.0
Hemicellulose % dry fibre	22.0
Lignin % dry fibre	19.0
Overall ethanol yield from fibre (L / t dry fibre)	340
Sugar price ($ /t IPS)	350
Ethanol price ($ /L)	0.70
Molasses price ($ /t)	90
Export electricity price ($ /MWh)	40

Table 4 – Input data for the scenario analysis

	Base scenario	Cogeneration scenario	Low ethanol scenario	Moderate ethanol scenario	High ethanol scenario
Trash collected (% cane)	0	10	10	10	10
Mixed juice to ethanol production (%)	0	0	0	70	100
Final molasses purity (molasses distillery feed purity)	45	45	45	72	-
Average boiler pressure (bar)	18	65	65	65	65
Average boiler efficiency (%)	60	72	72	72	72

Table 5 – Results from scenario analysis

	Base scenario	Cogeneration scenario	Low ethanol scenario	Moderate ethanol scenario	High ethanol scenario
Sugar produced (t IPS)	4 850 000	4 850 000	4 850 000	2 770 000	0
Molasses produced (t)	1 002 000	1 002 000	0	0	0
Ethanol produced from juice or molasses fermentation (ML)	60	60	316	1574	3248
Ethanol produced from cellulosic biomass (ML)	0	0	973	1159	1409
Total ethanol produced (ML)	60	60	1289	2733	4657
Export electricity produced (GWh)	1156	12 784	3122	2425	1493
% fibre required for combustion	100	100	61.8	54.4	44.6
Sugar revenue ($ m)	1698	1698	1698	970	0
Molasses revenue ($ m)	90	90	0	0	0
Electricity revenue ($ m)	46	511	125	97	60
Ethanol revenue ($ m)	42	42	902	1913	3260
Total revenue ($m)	1876	2341	2725	2980	3320
Sugar revenue (%)	90	72	62	33	0
Molasses revenue (%)	5	4	0	0	0
Electricity revenue (%)	3	22	5	3	2
Ethanol revenue (%)	2	2	33	64	98
% Australian automotive gasoline substitution[1]	0.3%	0.3%	6.7%	14.2%	24.2%
% Queensland automotive gasoline substitution[1]	1.3%	1.3%	28.8%	61.1%	104.1%

[1]2007-08 basis

Compared to the base scenario with revenue of $1876 m, the cogeneration scenario shows that an additional $465 m is able to be generated from increased electricity production with the installation of efficient high pressure boilers and generation equipment, energy efficient processing technologies and the combustion of additional trash. Significantly more income is able to be generated from the combined use of molasses, juice and bagasse for ethanol production with an additional $849 m possible in the low ethanol scenario, $1104 m possible in the moderate ethanol scenario and an additional $1444 m possible in the high ethanol scenario.

Further income is possible from the cellulosic ethanol production process if a valuable co-product is able to be made from the lignin component of the fibre. Work at QUT is continuing on developing effective strategies for integrated processing facilities manufacturing a diverse range of products in a sugar and ethanol based biorefinery.

Conclusion

With a sugarcane crop of 35 Mt, ethanol produced from sugarcane has the potential to meet a very significant proportion of Australia's current automotive gasoline requirements. In a possible moderate ethanol production scenario that includes trash collection and cellulosic ethanol production, sugarcane has the potential to provide sufficient ethanol to meet 14% of Australia's (or 61% of Queensland's) automotive gasoline requirement while not consuming any additional coal or other supplementary fuels.

Through crop expansion or the co-processing of other renewable fibres (such as sweet sorghum or green waste), further ethanol production may even be possible. Higher ethanol production quantities are also possible with the cultivation of higher biomass sugarcane varieties and the cultivation of varieties with a higher proportion of total fermentable sugars.

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