BIOMASS AND BIOENERGY 34 (2010) 1978–1981

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Short communication

Should straw/stover be turned into syndiesel or ethanol?

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ARTICLE INFO

Article history:
Received 16 September 2008
Received in revised form
23 July 2010
Accepted 27 July 2010
Available online 23 August 2010

Keywords:
Straw
Corn stover
Agricultural residues
Lignocellulose
Ethanol
Fischer Tropsch

ABSTRACT

Straw and corn stover can be used to produce ethanol by enzymatic hydrolysis and fermentation, or syndiesel by oxygen gasification and Fischer Tropsch (FT) reaction. FT has a higher processing cost and a higher energy yield of liquid transportation fuel. We analyze the cost of produced liquid fuel as a function of the field cost of biomass. At 80 \$ t^{-1} (dry basis) a crossover point is reached. Below this value, the cost of producing energy as ethanol is lower; above this value, FT syndiesel is lower. However, the crossover point occurs at a very high field cost of biomass, more than 5.50 \$ GJ^{-1}, and ethanol plants are less capital intense than FT and hence have a smaller economic size. For both reasons ethanol is likely to be the preferred processing alternative.

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To make a significant contribution to the energy mix, biomass must be converted into alternate energy forms, such as electrical power or a transportation fuel. Straw or corn stover can be converted into electrical power by direct combustion in conjunction with a conventional steam cycle, or by biomass integrated gasification to make a low heating value gas followed by combined cycle conversion to power (BIGCC). BIGCC has a higher processing cost per unit output (operating cost plus capital recovery) than direct combustion and higher conversion efficiency to electrical power [1]. Similarly, straw/stover can be converted to ethanol for use in internal combustion engines by enzymatic hydrolysis followed by fermentation of produced sugars, with generation of electrical power from byproduct lignin, or it can produce a synthetic diesel by oxygen gasification of biomass followed by a Fischer Tropsch (FT) reaction designed to maximize diesel production. Conversion of biomass to syndiesel has a higher processing cost per GJ of product and higher energy yield of liquid transportation fuel than production of ethanol [1].

The delivered cost of biomass consists of two components, the field cost of biomass and the cost of transportation to a processing plant. Field cost depends on payments to owners; one factor is the alternate value of the biomass. This can be positive (for example compensation paid to a farmer for nutrient replacement) or negative (for example, avoided disposal cost of mill residue). For a given size of processing plant, transportation cost will depend on the amount of biomass per total area in a region (gross yield), the fraction of that biomass available for sale to a processing plant (gross availability) and the cost of transport. Gross availability of biomass determines the transport distance for a given processing plant capacity. Transport cost is influenced by average

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doi:10.1016/j.biombioe.2010.07.029

transport distance, load size, fuel cost and average driving speed. The result of all these factors is that the delivered cost of biomass can have a wide range, from a negative value to a very high delivered cost.

The processing technology with the lowest unit product cost can depend on the delivered cost of biomass [2]. Consider two processes, with one having a higher product yield and a higher processing cost. If the increase in yield is a higher percentage than the increase in processing cost, the more expensive process will always be more economic. However, for production of power from biomass the increase in processing cost for BIGCC vs. direct combustion is higher than the increase in yield. In this case, as the delivered cost of biomass increases it reaches a point where it justifies a more expensive process for the gain in efficiency. This occurs because the more efficient process requires less biomass feedstock per unit of output, or alternately produces more saleable product per unit of biomass input. In the extreme, if biomass is free then there is no economic incentive to be efficient; if biomass is very expensive one cannot afford an inefficient process.

In previous work we estimated processing cost and energy yield for power production from straw/stover based on a wide range of available studies. We then calculated the feedstock cost above which power from BIGCC has a lower product cost than from direct combustion: 330 \$ t^{-1} (dry basis), which results in a power cost of 175 \$ MWh^{-1} [1]. These values are based on an optimum plant size that gives the minimum power cost for a region with a conservative biomass gross availability of 0.2 t ha^{-1} (dry basis). For a discussion of optimum plant size in biomass projects, see [1,3–9]. Given that BIGCC has a higher power production cost until the delivered cost of biomass is relatively very high, well above typical wholesale power costs of 50–80 \$ MWh^{-1}, direct combustion is the preferred technology for turning straw/stover into electric power.

We have extended this analysis to calculate the delivered cost of straw/stover at which the production of syndiesel from oxygen gasification and FT has a lower product cost per GJ than lignocellulosic ethanol for the same values of biomass gross availability, 0.2 t ha^{-1}, and for plants at optimum size. From a prior review of a wide range of studies of the cost of producing ethanol and FT syndiesel [1] we estimate the processing cost to be

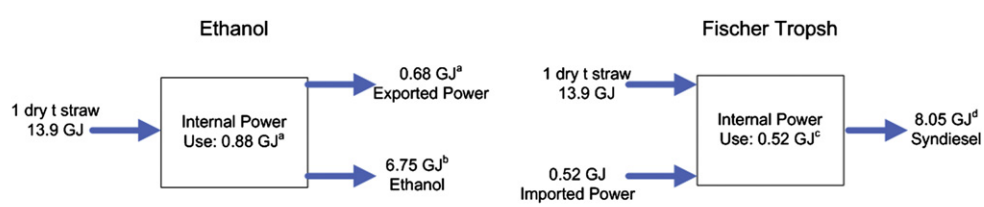
$$2006US\$\ (dm^{-3})\ \text{of ethanol} = 1.40\ (\text{Plant Size, } dam^3\ y^{-1})^{-0.3}$$

$$2006US\$\ (dm^{-3})\ \text{of syndiesel} = 3.02\ (\text{Plant Size, } dam^3\ y^{-1})^{-0.3}$$

In each case the implicit scale factor is 0.7. This processing cost includes the cost of capital. Actual projects would use a mix of equity requiring about an annual 12% after tax return and debt with a lower return. The processing cost calculation includes an annual 12% pre-tax return on total capital as a proxy for a blend of debt and equity financing. Heating values (LHV) per liter used in this study were 21.1 MJ for ethanol, 35.0 MJ for gasoline, and 36.4 MJ for diesel [10]. The efficiency analysis for liquid transportation fuel is more complex than for power generation, since lignocellulosic ethanol produces electrical power for export while FT configured to maximize diesel production imports power. Electrical power has a high value but its long term average price is far less volatile than gasoline or diesel fuel. Fig. 1 shows the yield values used in this study based on LHV. When the LHV of straw/stover input is 13.9 GJ t^{-1} (dry basis), the net energy output of FT is 7.53 GJ t^{-1} (dry basis), vs. 7.43 GJ t^{-1} (dry basis) for ethanol production. However, FT has a higher energy yield of liquid transportation fuel.

In this study we fixed the price of electrical power at 60 \$ MWh^{-1} and calculated the cost of producing one GJ (LHV) of transportation fuel as the field cost of biomass increased due to a higher acquisition cost. Plant size in this study is at optimum, i.e. the size at which total product cost is minimized. Table 1 summarizes plant size and processing and transportation cost.

Fig. 2 shows the product cost as a function of the delivered cost of biomass. At a field cost of biomass above approximately 80 \$ t^{-1} (dry basis) FT syndiesel has a lower net product cost than ethanol. The cost of syndiesel and ethanol at the crossover point is 28 \$ GJ^{-1}, which is equivalent to a wholesale price of 0.98 \$ dm^{-3} of gasoline and 1.01 \$ dm^{-3} of diesel. This range of gasoline and diesel wholesale price would occur with an oil price of about 130 \$ bbl^{-1}. Note that the crossover occurs not because the overall FT process is more energy efficient than ethanol, but rather because it produces more liquid transportation fuel. Also of note are the uncertainties in cost and yield numbers used in this study, and the shallow nature of the curve crossing in Fig. 2. The combination of these two factors makes the potential crossover point very broad.



[a] Derived from values reported in Refs. [11–13].
[b] Ref. [11].
[c] Ref. [14].
[d] Consistent with Refs. [15–18].

Fig. 1 – Energy yield for the production of ethanol and FT syndiesel from a dry ton of straw/stover.

Table 1 – Summary of plant size and production and transport costs for ethanol production and FT synthesis.

	Ethanol	FT Syndiesel
Plant Size (t d^{-1}, dry basis)	6750	12750
Plant Size (dam^3 y^{-1})	700	930
Draw Radius[a] (km)	230	315
Processing Cost[b]		
(t d^{-1}, dry basis)	58	86
($ dm^{-3})	0.18	0.39
($ GJ^{-1} liquid fuel)	8.7	10.7
Transport Cost of Biomass		
(t d^{-1}, dry basis)	44	58
($ dm^{-3})	0.14	0.26
($ GJ^{-1} liquid fuel)	6.63	7.14

a Based on a gross yield of 0.2 t ha^{-1} (dry basis).
b Includes capital recovery for a 25 year plant life at 12% annual pre-tax return on total capital.

1. Discussion

Studies of the cost of competing technologies for processing biomass are based on cost and yield data of different quality. Enzymatic hydrolysis of biomass and fermentation to ethanol is a widely researched process that is being applied at a commercial scale in six plants in the United States [19]. Oxygen gasification of biomass has never been applied at a large scale, and challenges of feedstock handling and dealing with produced slag and ash remain technical challenges. Studies of the cost of FT syndiesel from biomass show a far higher scatter than estimates for lignocellulosic ethanol [1]. Hence the specific values of the cost of biomass at which FT has a lower product cost than ethanol may change significantly as better estimates of the cost and yields of the two processes become available. The underlying point will not likely change, however: at some delivered cost of biomass FT syndiesel will have a lower cost per GJ than ethanol because it has a higher energy yield of liquid transportation fuel.

A second feature of this study bears comment: results are based on plants built at optimum size. For a high capital cost process such as FT the optimum size is very large, and might well exceed either the availability of biomass in a region or the financial capacity of an investor. A crossover point will be affected by the size of plants being compared. Recent work notes that the cost penalty for building plants at about half of optimum size is small, an increase in production cost of about 3%, although at still smaller sizes production cost increases rapidly [1]. Thus a lignocellulosic ethanol plant could be built at about 3000 t d^{-1} (dry basis) with a minimal cost penalty. If an FT plant were built at the same size, the crossover at which FT could produce liquid fuel for a lower cost per GJ than lignocellulosic ethanol would be a field cost of more than 100 $ t^{-1} (dry basis).

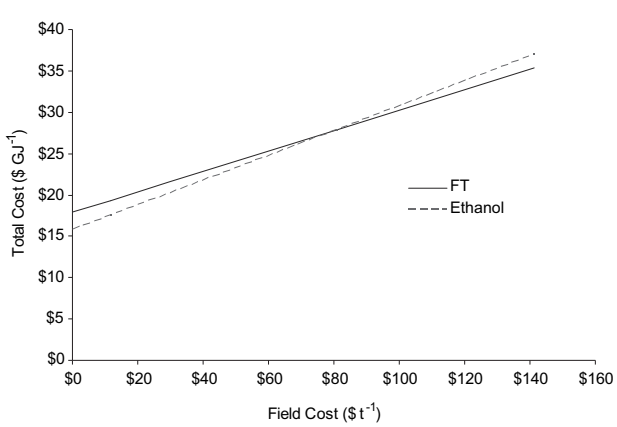


Fig. 2 – Cost of ethanol and FT syndiesel as a function of the field cost of biomass.

We note that a crossover between the NPV of FT and ethanol occurs with rising oil price only because the cost of electricity does not rise proportionally. Based on current yield data lignocellulosic ethanol and FT produce virtually the same amount of energy per unit of straw/stover input, but FT produces more energy as liquid fuel. Long term average power price has not shown the high volatility that has occurred for oil. A rise in oil price that is not matched by a rise in power price would cause FT to have a higher NPV than ethanol.

Finally, we note that this study suggests that lignocellulosic ethanol is and will remain a preferred processing alternative to FT. FT has a higher production cost until very high field costs of biomass: 80 $ t^{-1} (dry basis), the crossover point for plants built at optimum size, is equivalent to more than 5.50 $ GJ^{-1}, a cost that is an order of magnitude higher than the cost of surface mined coal. Many sources of biomass are expected to be available at a field cost significantly below 80 $ t^{-1} (dry basis) [20]. FT suffers from a second problem: it is far more capital intense than ethanol production, a problem in its own right for developers, but it further means that a larger plant size is required to benefit from the economy of scale, further increasing the development risk. For these reasons, subject to the uncertainty inherent in current cost estimates, we expect lignocellulosic ethanol to be chosen over FT for the production of liquid transportation fuel from biomass.

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