THE POTENTIAL FOR CELLULOSIC ETHANOL PRODUCTION IN CHINA

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Abstract

China became a net importer of energy in 1993, and petroleum imports increased to about 8.24 billion barrels in 2004, amounting for about 25% of total oil consumption in China. As a result of its continued growth, China now faces very serious energy shortages and environmental pollution problems. Thus, the Chinese government is encouraging ethanol use as an alternative transportation fuel by introducing fuel ethanol production and distribution within several provinces as part of the Tenth Five-Year Plan (2001-2005). Although the current emphasis is on ethanol production from corn and other grains, China has huge quantities of low cost cellulosic biomass such as corn stover, wheat straw and rice husk that could significantly expand ethanol production volume and reduce feedstock costs. However, a number of important issues mush be addressed including: Is there actually enough biomass to make a significant impact on energy supplies in China? How could cellulosic ethanol benefit China's energy security? Is production of cellulosic ethanol technically and economically feasible in China? Are appropriate technologies available for China? If not, what are the economic impacts if we use the best potential US technologies apply to Chinese market? This presentation will analyze the situation with regard to these questions to provide a perspective for government, industry, and academics of the benefits that cellulosic ethanol could potentially offer now and in the future.

Key Words: Energy, Biomass, Economics, Cellulosic Ethanol, China

Energy Challenges Facing China

Currently, U.S. consumes about 28% of the world oil supply while China uses about 6%. Over the last year, China produced about 12.9 billion barrels of petroleum, which ranked the country fifth in the world for the thirteenth straight year. Oil production has been maintained at this level for many years and is not expected to increase significantly. Thus, China imports about 25% of its oil from other countries including Saudi Arabia, Oman, Angloa, Iran and Russia [1].

Although per capita oil consumption in China is only one-fourteenth of that in the United States, demand is anticipated to grow with a rapidly increasing GDP that grew 3.8% in the final quarter of 2004 and 9.2% in the first 2005 quarter [2]. Furthermore, the transportation sector is projected to expand from roughly 24 million vehicles now to 90-140 million by 2020 [2], pushing the demand for transportation energy from 33% of total Chinese petroleum use to about 57% (from 1.6 million b/d in 2004 to roughly 5.0 million b/d in 2020). As a result, the International Energy Agency (IEA) projects that Chinese petroleum demand in 2030 will grow to just under 14 million bpd, about one-third less than the current demand in the United States [2]. Unfortunately, China's dependence on imported oil is also projected to continue to grow, reaching 75% of its petroleum use in 2030 and a quantity equal to that for the United States in 2004. Consequently, carbon dioxide emission from fossil energy will grow to 7.14 Gt/y in 2030 [1] (Table 1). Thus, China is faced with mounting challenges of meeting energy demand and addressing pollution.

Table 1. IEA current estimates and projections of liquid fuel needs for China in 2030 [1]

Liquid Fuel Use for Transport	12.4 EJ/y
Liquid Fuel Use for Transport increment, 2002-2030	9.04 EJ/y
Total Coal Use	56.7 EJ/y
CO2 Emission from Fossil Energy	7.14 Gt/y

The Desirability of Cellulosic Ethanol in China

The Renewable Energy law was passed in China on February 28, 2005 to accelerate the development of renewable energy, including wind, solar, hydro, and biomass. China initiated research on the supplementation of gasoline with ethanol in 1999. In February 2004, exclusive use of gasoline containing 10% ethanol was initiated in all areas of Heilongjiang, Jiling, Henan, and Anhui provinces and in selected areas of Hebei, Shandong, Jiangsu, and Hubei provinces. Furthermore, it was made illegal to sell or purchase gasoline not containing 10% ethanol in these areas.

The government invested in four factories in Heilongjiang, Henan, Jiling, and Anhui provinces to produce fuel ethanol from grain, with corn the primary feedstock. Xinglong Energy Inc. in Jiling, with an annual capacity of 250 million gallons of ethanol, is the biggest fuel ethanol producer, and China expects to achieve a total annual fuel ethanol production capacity of about 534 million gallons in the near future [3]. Initially, these processes targeted the use of grain that was stored for war supply so long that it was no longer suitable as food or animal feed. In addition, fresh corn was also targeted to compensate for its overproduction in certain areas. However, the government is concerned that the farmers will loose money once cheap American corn dominates the market as China enters the WTO. Thus, the government introduced policies to promote production of grain-based ethanol, such as eliminating sales tax and providing subsidies to compensate for any revenue loss during processing and sale. Meanwhile, the government set the selling price of ethanol as 91.1% of the selling price of gasoline, which is about \$1.65/gallon. However, production of corn-based ethanol costs about \$1.84/gallon (if the price of corn is \$147 per dry ton), resulting in large payments of subsidies by the government. The planned phase down of these subsidies means that ethanol producers will need to significantly reduce production costs within a couple of years, a situation that will be exacerbated as aged grain runs out and more expensive fresh corn must be used. Furthermore, China has a population of 1.3 billion to feed, potentially driving up corn prices and begging the question of whether there is enough corn to meet the demand for food and fuels.

Cellulosic biomass, such as agricultural and forestry residues, major portions of municipal solid waste, and dedicated herbaceous and woody crops, provides a meaningful alternative feedstock for ethanol production [4]. These materials are low in cost and potentially perpetually available in abundant quantities to realize meaningful energy security, balance of trade, and rural employment benefits in China. For example, cellulosic biomass costs about \$22/dry ton including transportation cost in China (\$42/dry ton in US), which is equivalent to about \$13/barrel petroleum based on supplied energy [5]. Furthermore, cellulosic biomass is much less expensive than corn at current prices of about \$147/dry ton (Chinese government regulated price, 2004). The challenge for large-scale commercialization is to reduce processing costs through applying the continually evolving tools of biotechnology to enhance performance and reduce costs and to make valuable coproducts that improve profitability[6].

Cellulosic Resources for Ethanol in China

China is an agricultural country. Almost all the land mass suitable for planting has been used and lignocellulosic biomass is abundant. The principle lignocellulosic biomass resources in China include recoverable crop residues, forest industry residues, dung, and biomass energy plantations [7]. As shown in Table 2, the potential availability of biomass in China was predicted. For forest industry residues, it is assumed that three-fourths of milling and manufacturing wood wastes and one-fourth of the forest residues are recoverable[8]. For animal dung, it is projected that one-eighth of the generated dung could be used as feedstock [8]. It is also determined that biomass energy plantations could have an average yield of 15 dry ton per hectare per year and could be established on 10% of the total land now employed for forest/woodlands, croplands, and permanent pastures [8]. Thus, total biomass production is anticipated to reach 23.33 EJ per year by 2030, roughly equivalent to 4 billion barrels petroleum.

Table 2. Estimated Annual Potential Production of Biomass for Energy in China by 2030, EJ/y[8]

Recoverable Residues				Biomass Energy Crops	Total Bioenergy Production
Crops[7] (by 2030)	Forest	Animal Dung	Total Residues		
5.53	0.9	0.6	7.03	16.3	23.33

When we compare the projections of table 2 with the anticipated need for 12.4 EJ of fuel for transportation, we can see that sufficient biomass could be available to meet the future demand for fuels in China. Furthermore, ethanol made by biological processing of cellulosic biomass generate little if any net greenhouse gas emissions and offers a powerful route to sustaining both the environment and resource supply[4,9-12]. A few systematic studies were undertaken on processing of cellulosic biomass to ethanol in China because of its environmental, security, and economic advantages since the early 1970s. However, because cellulosic ethanol was eventually ignored in Chinese energy policy and the Chinese fuel ethanol industry is in its infancy, many barriers must be overcome before low cost cellulosic biomass sources can make a significant impact on the future of Chinese energy. In 2005, China promoted the National Key R&D Program (863) on cellulosic ethanol as a step in this direction. The comparison of conversion yields of corn ethanol between China 863 target and two U.S. models (e.g., NREL 2002 model [14] and Mature model [15]) is shown in Table 3. The U.S. NREL 2002 model and mature model represent technology available within several years and 25 years, respectively. Conversion yields of cellulose and xylan in the NREL model were close to those in the China 863 targets.

Table 3. Comparison of conversion yields of corn stover in China and U.S.

	China 863 target 2005	NREL 2002 [14]	Mature model [15]
Cellulose to glucose	0.9	0.9	0.95
Xylan to xylose	0.8	0.9	0.95
Glucose to ethanol	0.85	0.95	0.95
Xylose to ethanol	0.85	0.85	0.95
Mannan to mannose	-	0.9	0.95
Mannose to ethanol	-	0.85	0.95
Arabinan to arabinose	-	0.9	0.95
Arabinose to ethanol	-	0.85	0.95
Galactan to Galactose	-	0.9	0.95
Galactose to ethanol	-	0.85	0.95

Case Study for Henan Province

With 6.825 million hectares of arable land, Henan is a well-known major agricultural province in central China and an important producer of agricultural and sideline products. The annual availability of corn stover is about 20 million dry tons in Henan. Henan is also one of the provinces that enforce addition of 10% ethanol to gasoline. Currently, over 23 million gallons of gasoline is consumed annually in Henan, and consumption is expected to increase with the rapid growth in automobile use as evidenced by the issue of over 200 new automobile plates each day in the province capital. If an ethanol yield of 100 gallons ethanol per ton corn stover is realized, only 1.1 million tons of corn stover, corresponding to just 5% of the amount generated each year, is needed to produce 134 million gallons of ethanol to fill the current 10% ethanol blending market for Henan. In this situation, about 5,000 dry tons per day of corn stover from a land area of about 5,000 km^2 would be sufficient to serve the plant. When all costs of residue gathering, storage, and transport are included for an average residue transport distance of about 100 km, the delivered residue cost would be about $22 per dry ton —a cost that is likely to be a conservative estimate for China, because of the lower labor cost [13].

Economics of Cellulosic Ethanol

To estimate the cost of producing cellulosic ethanol in China, two cellulosic ethanol technoeconomic assessments were adapted to reflect the situation in China. The first was reported by NREL in 2002 to represent near-term technology available within a few years. The second was based on an estimate of what mature, advanced technology would look like within 25 years. Major differences between the NREL model and the mature model are outlined in Table 4.

Table 4. Major differences between NREL and mature models

	NERL model [14]	Mature model [15]
Major process operations	Acid pretreatment Purchase enzyme Separate enzymatic hydrolysis and ethanol fermentation with lower yields	AFEX pretreatment Consolidated bioprocessing with higher yields
Plant scale, ton corn stover/day	2000	5000
Corn stover, $/ton	30	40
Ethanol, MM gal/y	69.3	184
Generated Electricity, MM kw/y	157	1057
Financing	100% equity	40% debt/60% equity

It would be ideal to estimate equipment costs based on Chinese conditions as some equipment could be made in China and might cost only half of what it would cost in the U.S. However, estimation of equipment costs in China is complicated, and in the interest of the time available for this study, it was assumed that equipment costs would be the same as for the U.S.. On this basis, capital cost estimates for the NREL and mature models are shown in Table 4. Fortunately, variable and fixed operating costs could be more readily estimated for Chinese circumstances. Of the variable operating costs, the feedstock cost in China is estimated as $22/ton to be about half that in U.S. mature model and a bit lower than that in U.S. for the NREL model. Since the average electricity price in China (i.e. $0.623/kwhr) is close to the average electricity price in the U.S. (i.e. $0.666/kwhr), the selling price of excess generated electricity was not changed. For the fixed operating cost, average salary rates in foreign invested plants in big cities of East China, which are usually relatively high, were used.

Based on these capital and operating cost estimates, a minimum ethanol selling price was estimated that would result in an internal rate of return (IRR) on capital of 10% or 12% using a discounted cash flow that results in a net present value of zero after 20 years. When adapted to Chinese conditions, the minimum ethanol selling price decreased by 11.5% and 33.9% for U.S. NREL and Mature models to $0.95/gallon (RMB 2.02/L) and $0.43/gallon (RMB 0.92/L), respectively (Table 5). By comparison, the current fuel ethanol price in China, which is set as 0.911 of the price of gasoline by the Chinese government, is on average of $1.65/gallon (RMB 3.53/L) (tax included). Even if the cost of corn stover increased to $30/ton as for the U.S. NREL model, the Mature model projects that the minimum ethanol selling price for China is still promising at $0.484/gal (RMB 1.03/L). Thus, these simple estimates suggested that application of U.S. cellulosic ethanol technology in China is economic feasible.

Table 5. Comparison of process economics in China and U.S.

	China		U.S.	
	NREL	Mature	NREL	Mature
Total project investment, MM$	197.4	396.9	197.4	396.9
Variable operating cost, MM$/y	24.54	2.44	31.5	37.44
Fixed operating cost, MM$/y	6.04	11.29	7.535	13.98
Internal rate of return, %	10	12	10	12
Minimum ethanol selling price, $/gal	0.947	0.4297	1.07	0.6504

Conclusions

China is promoting fuel ethanol use by requiring ethanol sales in several provinces and through subsidies for fuel ethanol plants. However, grain ethanol is faced with a number of important potential challenges that could impact its future. Fortunately, data from Henan Province suggest that enough cellulosic biomass is potentially available to meet the ethanol blending demand. Furthermore, operating costs are projected to be sufficiently low that ethanol could be made at costs competitive with current ethanol prices in China even if capital costs are assumed to those in the U.S.

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