A Cellulosic Bioproduct Economy

Danny G. Le Roy, K.K. Klein and Tatiana Cook

Department of Economics, The University of Lethbridge
Lethbridge, Alberta, Canada

INTRODUCTION

The rapid expansion of ethanol production from corn, wheat and sugar cane is driving up commodity prices everywhere. As the shortcomings and limitations of making ethanol from grain and cane become increasingly apparent, interest in using lingocellulosic materials to produce fuel is intensifying. Lignocellulose is the structural component found in all plant cell walls and is composed mainly of cellulose, hemicellulose and lignin. While lingocellulosic materials can be used to make a variety of goods including chemicals, materials, and other forms of energy, the end use for which demand is most acute is for ethanol production in the United States.

The Energy Independence and Security Act signed by President Bush on December 19, 2007 increases the current renewable fuel standard in the United States for 2008 from 5.4 billion gallons to 9 billion gallons, and sets a 2022 deadline for 36 billion gallons. As the upper limit of corn ethanol production in the United States is about 17 billion gallons, the leglisation also requires that, by 2022, 60 percent of biofuels must come from sources other than corn. Ethanol made from lignocellulosic materials will be essential to meet legislated production targets. The consequences will be greater and more widespread than any provincial or federal biofuel policy implemented in Canada.

Corn stover, straw, switchgrass, miscanthus, shrub willow, hybrid poplar and woodchips are examples of lignocellulosic feedstock that could be used to make ethanol. The resulting ethanol is chemically identical to that derived from corn, wheat or sugar cane. Lingocelluslosic materials are an attractive alternative because they are highly abundant, diverse and are often perceived as a “waste” co-product of other processes. Since lignocellulose is found in nearly every natural free-growing plant, tree, and bush in meadows, forests and fields, the opportunity costs of lignocellulosic production are typically low. The vast forested areas in North America contain massive amounts of lingocellulosic material that could be harvested and converted into ethanol. In addition, many agricultural processes generate lignocellulosic co-products (such as straw) that have potential as an input the manufacture of ethanol.

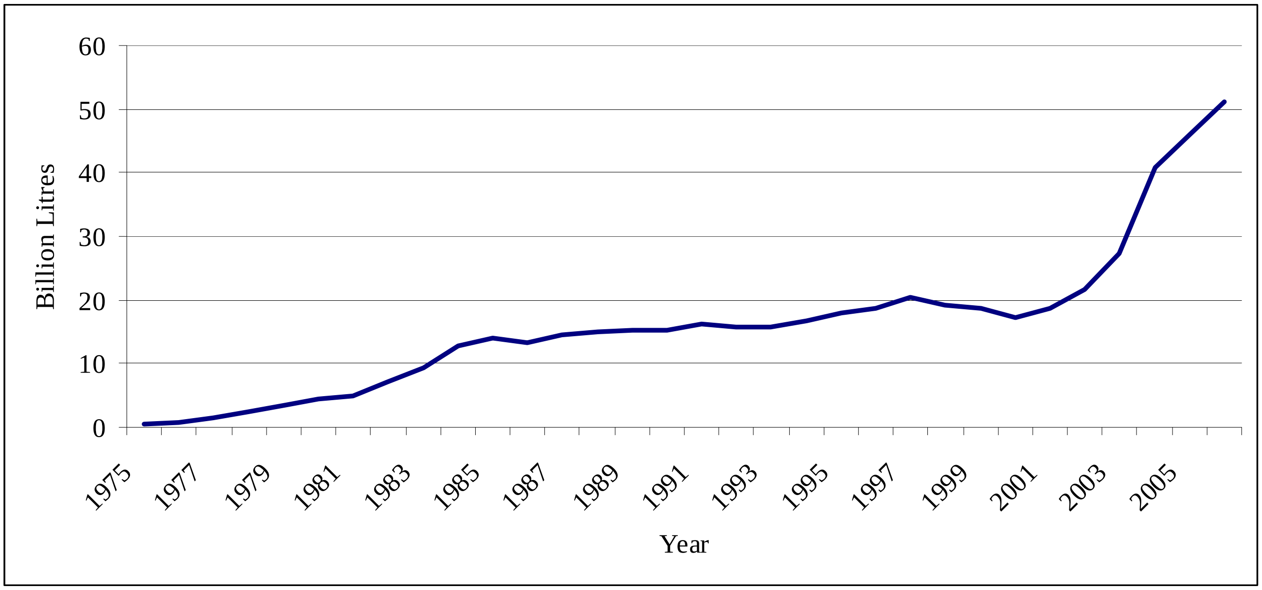
However, producing ethanol using lingocellulosic feedstock is also relatively more difficult and expensive as it requires additional processing and other costly inputs. To get at the fermentable sugars, the celluloses must first be removed from the lignin. The newly freed celluloses are then acid hydrolyzed to break them down into simple monosaccharides. A high percentage of the monosaccharides produced are *pentoses*, like *xylose*, or wood sugar, instead of *hexoses*, like *glucose*, which are easiest for microorganisms to ferment. Until recently, just the cost of the cellulase enzymes capable of hydrolyzing the celluloses alone made large-scale ethanol production prohibitively expensive.

The highest profile facet of the cellulosic bioproduct economy is the strong political desire to use lignocellusloic materials in the manufacture ethanol. For this reason, the purpose of this paper is to describe the main policies used to promote the production of ethanol made from lingocellulose and to delineate some economic implications.

BACKGROUND

Figure 1 shows the dramatic increase in ethanol production since the turn of the century. In 2000 total world production of ethanol for fuel was less than 18 billion litres. By 2006, production had almost tripled to about 51 billion litres. The United States is now the largest producer of ethanol in the world, having overtaken Brazil in 2005 (Renewable Fuels Association, 2007).

Figure 1: *Global Ethanol Production, 1975-2006*



Sources: Renewable Fuels Association, 2007.

Table 1 reveals that ethanol production in the United States and Brazil amounted to more than 35 billion litres of ethanol, a total which exceeded production from all other countries combined. Far behind the United States and Brazil, but in third place in world production, is China, where production approached 4 billion litres, followed by India with about 1.9 billion litres. In Eastern Europe, producers in the Russian Federation and Ukraine supply most of the output (646 million litres and 268 million litres, respectively). Production in many western European countries, notably France, Germany and Spain, has been increasing rapidly. Canada and South Africa had significant production of 578 and 386 million litres of ethanol, respectively, in 2006.

Table 1: *World Ethanol Production, by Country, 2006*

Country	2006	Country	2006
U. S.	18,357	Canada	578
Brazil	16,975	Spain	461
China	3,844	South Africa	386
India	1,897	Thailand	351
France	949	United Kingdom	279
Germany	763	Ukraine	268
Russia	646	Others	4,844
		Total	**50,988**

Source: Renewable Fuels Association, 2007.

The main feedstock used to produce ethanol in Brazil is sugarcane. Corn is the main feedstock for ethanol in the United States. Barley, cheese whey, waste beer, wheat, milo and wheat also are used to make ethanol. Some have estimated that in the near future, 20% of all corn grown in the United States will be used to produce ethanol.

The European Biodiesel Board predicts that the biodiesel industry in the European Union nearly doubled production in 2006 to 6.9 billion litres from the 2005 level of 3.6 billion litres (EBB 2007). Most of the biodiesel in Europe is produced in Germany. Ten percent of the 11.1 million hectares of arable land in Germany is set aside on which producers receive subsidies in exchange for not growing crops for food. However, growers can produce crops on the set aside acreage for the production of fibre or fuel. In response to government incentives, about 1.9 billion litres of biodiesel was produced in 2005 (and Germany was projected to produce over 3 billion litres in 2006) (EBB 2007).

France is the second largest producer of biodiesel in the European Union after Germany, producing 559 million litres in 2005 (with projections of 880 million litres in 2006) (EBB 2007). Italy has the third largest biodiesel production capacity in Europe. Unlike in Germany or France, the biodiesel produced in Italy is used not for transportation but for home heating in the domestic market. Conventionally produced heating oil is taxed at €58 per litre while biodiesel was tax exempt until recently. Biodiesel is produced in other European countries as well, especially in Czech Republic, Denmark, Austria, Sweden, Great Britain and Spain but production capacities and consumption are less than in Germany, France and Italy.

POLICIES TO SUSTAIN AND PROMOTE THE BIOFUELS INDUSTRY

To encourage production and consumption, governments in 41 countries have implemented policies that encourage the use of biomass and outputs from agricultural processes to produce biofuel. An International Food and Agricultural Trade Policy Council (2006) discussion paper identifies a long list of support measures used in various countries. These include fuel excise tax exemptions and rebates, production mandates of specified levels of biofuels, compulsory blending mandates with fossil fuels, government-procurement preferences and purchase mandates, local tax breaks on property taxes or and state/provincial taxes, accelerated write-off schedules for eligible biofuels-related capital, tax exempt bonds for finance (typically in the United States), subsidized loans, loan guarantees, special capital gains exemptions or deferrals on sale of bio-fuel plant and infrastructure, regulatory exemptions and waivers including environmental impact waivers, state (provincial) producer credits either for all producers or those below a certain size or having a certain organizational structure (e.g. farmers' cooperatives), state/provincial/federal subsidies towards purchase of vehicles and infrastructure that can use biofuels, environmental legislation mandating certain specific types of fuel additives (typically for fuel oxygenation) related to reducing vehicle exhausts, government purchases of surplus agricultural stocks for conversion to bio-ethanol (particularly wine in the European Union), subsidies not normally associated directly with biofuels, such as agricultural farm supports in the United States and the European Union and elsewhere and, finally, government supported research and development for biofuels ranging from basic research to technology demonstration plants.

The policies have a variety of objectives, including reducing greenhouse gas emissions, improving air and water quality by reducing toxins and air pollutants, reusing waste materials, enhancing and stabilizing returns for farmers, and increasing energy security. As a result, global demand is expanding for fuels derived from corn, sugarcane, and soybeans, or from biomass resources such as agricultural, wood, animal, and municipal wastes and residues. Ethanol and biodiesel have become the predominant biofuels because both can be substituted for gasoline and diesel or they can be blended with them.[1]

Government support for biofuels in Canada and in the United States now extends beyond ethanol and biodiesel produced from cereal and oilseed crops. On December 20, 2006, the federal government announced C$145 million transfer through the Agricultural Bioproducts Innovation Program to promote research, development, technology transfer and commercialization activities in areas such as biofuels, other forms of bioenergy, biochemicals, biopharmaceuticals, etc. In the Federal Budget which was presented just three months later, C$1.5 billion in subsidies were made available over seven years for producers of ethanol and biodiesel. Government assistance is up to C$0.10 per litre for renewable alternatives to gasoline and up to C$0.20 per litre for renewable alternatives to diesel for the first three years, after which point the subsidies are then to decline. In addition, transfers totalling C$500 million over seven years will be made to producers of ethanol from agricultural and wood waste products such as wheat straw, corn stover, wood residue and switchgrass.

The production of liquid fuels from lingocellulosic materials has been mentioned the State of the Union Address in both 2006 and 2007. In his State of the Union Address on January 31, 2006,

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[1] Biogas is also an important biofuel, but it has received relatively less political attention than ethanol and biodiesel. Created by the anaerobic digestion of food wastes, manure and other organic substances, biogas is used to substitute for natural gas for the purpose of generating electricity, heat and/or steam. At present, electricity generated from biogas in Canada is not competitive with traditional alternatives in most instances. To displace even a small proportion of domestic consumption, electricity generated using biogas will require relatively more government intervention than what is currently necessary for ethanol or biodiesel. The upshot is that ethanol is the major opportunity for mass-market biofuel in Canada.

President Bush stated: “We'll also fund additional research in cutting-edge methods of producing ethanol, not just from corn, but from wood chips and stalks or switchgrass. Our goal is to make this new kind of ethanol practical and competitive within six years.” In July 2006 the U.S. Department of Energy released a report with an ambitious new research agenda for the development of lignocellulosic ethanol as an alternative to gasoline.

In the 2007 State Of The Union Address, President Bush announced his “Twenty-In-Ten” plan to reduce United States gasoline usage by 20% in the next ten years. He suggested that Americans can reach that goal by setting a mandatory fuels standard that requires 133 million litres of renewable and alternative fuels in 2017, nearly five times the 2012 target that now is in place and nearly eight times the current level of production. If this ambitious target could be met, it would displace 15 percent of projected annual gasoline use in 2017.

To meet the Twenty-In-Ten objective and make lingocellulosic ethanol cost-competitive with gasoline by 2012, on February 28, 2007 the U.S. Department of Energy announced US$385 in transfers for six lignocellulosic biorefineries over the next four years. When fully operational, these biorefineries are expected to produce more than 130 million gallons of ethanol annually. Including the 60 percent industry share, the total investment in these plants will be approximately US$962 million, or roughly US$7.40 per gallon of capacity. Current costs for conventional ethanol plants are around US$2.20 per gallon.

Several federally subsidized research projects involving the production of ethanol from lignocelluloses are underway in the United States. Three research centers (Oak Ridge, Tennessee; Madison, Wisconsin; and near Berkeley, California) are receiving transfers totalling US$405 million to accelerate basic research into the development of cellulosic ethanol and other biofuels (DOE, June 26, 2007). Although funding was originally slated to begin in 2008, the Department of Energy has accelerated transfers with a supplemental US$30 million allocation in the final quarter of 2007 (DOE, October 1, 2007). Roughly US$34 million in cost-shared research funding is being directed to support research into cellulosic enzymes over (EERE News, August 27, 2007). Other subsidies include US$17.5 million over three years for cellulosic biomass conversion to help make it competitive with fossil fuels (DOE, October 11, 2006), US$23 million to support development of better cellulosic enzymes (DOE, March 27, 2007) and US$13 million to support product development from cellulosic feedstock (DOE, June 11, 2007).

According to Koplow (2007), total government support for biofuels in the United States reached approximately US$6.3–$ 7.7 billion in 2006, the majority of which was directed to ethanol. He projects total support to reach around US$13 billion in 2008 and almost US$16 billion by 2014. Under existing policies, the industry will, in aggregate, obtain subsidies worth more than US$92 billion over the 2006–2012 timeframe. These estimates are conservative as they do not incorporate many state subsidies now in effect nor the cost of a more stringent renewable fuels consumption mandate.

Table 2: *Firms Receiving Grants for Cellulosic Ethanol*

Developer	***Site***	***Production (million litres/year)***	***Feedstock***	***Amount***
Abengoa Bioenergy Biomass of Kansas	Kansas	43	635 tonnes/day corn stover, wheat straw, switch grass	$76,000000
ALICO, Inc. of LaBelle	LaBelle, Florida	53	700 tonnes/day yard, wood, and vegetative waste	$33,000,000
BlueFire Ethanol, Inc	Irvine, California	72	635 tonnes/day of sorted landfill waste	$40,000,000
Broin Companies of Sioux Falls, South Dakota	Emmetsburg, Iowa	473, 25% of which will be cellulosic	765 tonnes/day corn fiber, cobs, stalks	$80,000,000
Iogen Biorefinery partners, LLC of Arlingont, Virginia	Shelley, Idaho	68	635 tonnes/day agricultural residues: wheat straw, corn stover, switch grass and rice straw	$80,000,000
Range Fuels of Broomfield Colorado	Soperton, Georgia	151	1090 tonnes/day wood residues	$76,000,000

Source: DOE. 2007. February 28. http://www.energy.gov/news/4827.htm

IMPLICATIONS

The primordial justification for expanding biofuels in Canada is the reduction in CO_2 emissions that result from the displacement of petroleum-based energy. In the United States, it is the political desire for energy security. In each country, policy objectives are only partially realized and with large costs and other undersirable, unavoidable consequences.

Though a lot of fossil fuels are used in the production of first generation biofuels, life-cycle analysis generally reveals a reduction in greenhouse gases, carbon monoxide and other undesirable compounds. According to the Government of Canada (2006), consumption mandates are anticipated to lead to greenhouse gas emission reductions of 2.7 million tonnes per year on a life cycle basis. This reduction represents about one percent of the CO_2 reductions as of 2006 in order to achieve the federal government's Kyoto Protocol commitment. While still relatively expensive, there is a greater reduction in greenhouse gas emissions from production and use of lignocellulosic ethanol.

Despite increasing attention given to the limitations of large scale biofuel production, government subsidization continues to climb. Even using best estimates for ability of the fuel to displace petroleum, fossil fuels, and GHG emissions, biofuel subsidies are inefficient (Koplow, 2007). The same outcomes could be achieved for far less public money; or the same money could buy far more environmental improvements if deployed in a different way.

Trade-offs are central, inevitable features of renewable energy policy as are all decision made under conditions of scarcity. Desired environmental benefits do not come without environmental costs. Expanding ethanol production in the United States has worried some that cropland will be shifted from the Conservation Reserve Program to provide more land on which to plant corn and other energy crops (Shapouri 2007). This could happen in Canada as well. Following the end in 1995 of the Western Grain Transportation Act (that subsidized the freight rates to transport grains from the prairies provinces to export terminals and, therefore, artificially increased feed grain prices on the prairies), some land around the fringes of the main crop growing areas were taken out of crop production and planted to grasses and other perennials. This was a more sustainable use of fragile soil resources in these regions. However, the rapid rise in grain prices (and the subsequent economic stress this places on the livestock industry) threatens to reverse this activity. It seems likely that marginal quality land (i.e., land that is easily erodable, has higher salt content, or other characteristics that make it environmentally sensitive) will be converted to energy crop production.

There also is the issue of water use to produce biofuels. Production of one litre of cereal based ethanol requires between four and eight litres of water, depending on the process used. Depending on the process used, ethanol production from cellulosic materials could require even more. Most of the water must come from underground sources and this could reduce the level of water tables. In many regions, increased demand for water resources by industry, agriculture, municipalities, and recreation is threatening this already scarce resource. Widespread use of water to produce transportation biofuels could further threaten its sustainability.

The profitability of biofuel production is largely determined by the price of competing outputs, principally petroleum products, and the cost of its feedstock, mostly cereal grains and oilseeds. The prices of petroleum and agricultural crops are notoriously variable. This, combined with the uncertainties involved in agricultural crop production presents several risks for biofuel producers.

While the increased prices of grains may limit future expansion of the cereal based ethanol industry rising ethanol prices makes production from lingocelluslosic materials more competitive. Virtually all countries that are involved in the production of biofuels have programs that support biofuel research, much of it aimed at developing more efficient processes for converting plant-based starches to alcohol. A wide variety of new processes are under investigation, including gasification and Fischer-Tropsch synthesis. Although these new processes are not competitive at present, research may result in breakthroughs in cost efficiency.

The greatest potential cost reductions lie in the development of technologies that convert cellulosic feedstock to ethanol, and eventually to hydrogen and other liquid fuels like synthetic diesel. Ethanol derived from cellulosic materials requires greater processing than that required for converting starch or sugar based feedstocks to ethanol. The cost of cellulosic feedstock, including grasses, harvest residues and trees generally is much lower than that of cereals. However, the additional costs of handling, storage and transportation of the bulky materials can significantly increase average costs of production (Miranowski, 2007). Iogen Ltd, a Canadian-based company, has developed an advanced new technology to make ethanol from biomass. The process combines innovations in pre-treatment, state-of-the-art enzyme technology, and advanced fermentation technology. Pre-treated cellulosic fibre is converted to sugars using enzymes; sugars are subsequently fermented to ethanol; and ethanol is purified to fuel.

As a result of on-going research, the International Energy Agency estimates the cost of producing a litre of ethanol made from cellulose (poplar trees) to decline by about half within ten years and the cost of producing a litre of ethanol from corn in the United States to decline by about 14% in the same timeframe (IEA, 2004). The International Energy Agency also projects that with continued research and development, "the cost of both ethanol and sugar cane in Brazil (and probably in many other developing countries) and cellulosic ethanol in all regions of the world have the potential to reach parity or near-parity with the cost of gasoline, with oil prices between $25 and $35 per barrel" (IEA, 2004: 84). With oil prices in the last couple years about triple that level, this may happen much sooner.

Although the cost of oil has increased substantially recently, it generally remains true that the cost of producing biofuels, particularly lingocellulosic ethanol, is still substantially higher than the cost of petroleum fuels (IEA 2004). However, a lot of evidence exists that production costs are much lower in the developing countries that lie in tropical and sub-tropical areas with low land and labour costs. Crops such as sugarcane, tapioca, sorghum, and cassava have been used as feedstocks for ethanol production. Palm oil, soybeans, peanuts, cocoanut, and jatropha have been used to produce bio-diesel. In Brazil, the costs of producing ethanol from sugarcane are now similar to (or less than) the cost of petroleum fuels. In other tropical and sub-tropical countries, especially in Thailand and the Philippines, major new initiatives have been implemented to boost production of biofuels (F. O. Lichts, 2005).

CONCLUDING REMARKS

It is unclear at this time if a commercial cellulosic ethanol plant will become a reality in Canada in the near future. Certainly, there is a great quantity of crop residues that are available for use each year. However, the relatively short growing season makes it difficult to achieve high yields. The logistics and costs of harvesting, collection, storage and distribution of the huge quantity of bulky materials required to supply the feedstock requirements for a commercial ethanol plant throughout the year are the biggest obstacles. More research is necessary to make the purification of sugar more economically feasible and to improve ethanol yields from *pentose* sugars like *xylose*.

The United States Department of Energy recently awarded grants to six cellulosic ethanol projects. It is hoped that the experience gained from these initial plants will provide information to reduce the cost and logistical problems. The resolution of these and related problems are required to meet the political objective in the United States of having lignocellulosic ethanol as a cost-competitive alternative to gasoline by 2012.

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