Forests as a Potential Feedstock for Cellulosic Ethanol

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Summary

President George W. Bush set a goal of producing 35 billion gallons of renewable and alternative fuels by 2017. Limits on the potential growth of ethanol production from corn have increased interest in producing ethanol from cellulosic plant materials, but the cost of producing ethanol from cellulosic materials is prohibitively expensive relative to corn ethanol. Therefore, Congress has recently authorized both federally mandated levels of cellulosic ethanol and financial subsidies to producers. The question addressed by this paper is whether or not these incentives will have a significant impact on the use of wood from existing forests to produce ethanol.

Wood is already a valuable source of energy for heating, industrial use and power generation. As oil prices increase the use of forests for energy will undoubtedly increase as well. This new focus on cellulosic ethanol has created much interest in the potential for forest residues as a feedstock. Such interest might bring new public focus to the potential for forestry to help provide for the nation's needs, and create a potential market for small diameter trees. There is also hope that revenues from ethanol feedstock could help to fund forest fuels reduction and ecosystem restoration activities. However, this study has revealed that it is unlikely that residues from existing forests will play a significant role in ethanol production in the foreseeable future. There are four important factors that lead to this conclusion.

1) Ethanol produced from forest residues harvested on federal lands neither qualifies for production subsidies, nor contributes to production targets. Due to the high cost of cellulosic ethanol production these federal mandates and subsidies will be the primary drivers for future production.
2) Much of the forests needing fuel treatments are in arid lands where there is insufficient water to supply ethanol plants. More generically, there is a mismatch between where the forest resources are located, where the ethanol refineries will likely be located, and the prohibitive cost of transporting residues (both in dollars and greenhouse gas emissions).
3) Nearly all existing industrial forest residues already have higher valued uses. In fact, much of the industrial residue is already consumed to produce energy.
4) Delivered biomass from forest residue is expected to have higher delivered costs and lower yields relative to other sources of readily available feedstock (like agricultural wastes and short rotation woody crops). Research is already underway to produce hybrid short rotation woody crops genetically designed for high ethanol yields.

From a supply point of view, this study suggests that between 64 and 129 million dry tons of recoverable woody biomass is potentially available under more favorable economic conditions than those existing today. This supply could offset two to four percent of the nation's current gasoline requirements at best. However, this available biomass would not become a significant source of feedstock for ethanol production until all commercially viable agricultural wastes and short rotation energy crops have been fully utilized. In the meantime this available biomass could be an important source of feedstock for more cost effective wood energy technologies. A broader wood energy white paper should be written to explore the relative benefits of different wood energy opportunities.

Background

In his 2007 State of the Union Address, the President set a goal of producing 35 billion gallons of renewable and alternative fuels by 2017. Such a production level would replace 15 percent of projected fuel consumption. In December 2007 the Energy Independence and Security Act was signed into law calling for the production of 36 billion gallons of renewable biofuels by 2022 (CRS 2007b). The act takes effect in January 2009.

In the U.S., ethanol was first seen as a major solution to reduce greenhouse gas emissions, reduce oil imports (increase energy independence), improve fuel security, and utilize a surplus of corn. More recently, however, some scientists, environmentalists and the media have become increasingly critical of ethanol – especially ethanol produced from corn. For example, Hill et al. (2006) conducted a thorough life-cycle analysis and found that ethanol produced from corn only gives a 25 percent net energy gain over the energy used to grow the corn and refine the ethanol. This energy gain is mainly due to co-products produced from the process (animal feed) – not the ethanol itself. Corn also has serious negative environmental impacts (Pimental and Patzek 2005). It causes more soil erosion and uses more herbicides, insecticides and nitrogen fertilizer than any other US crop. This causes water pollution that affects habitats and aquifers. Diversion of corn crops to ethanol impacts food prices. Finally, corn ethanol production requires high quality agricultural lands that are currently fully utilized.

For example, in 2004 11% of the nation's corn harvest was used to produce 3.4 billion gallons of corn ethanol. Production increased from 3.9 billion gallons in 2005 to 6.5 billion gallons in 2007. This represents roughly 4.6% of gasoline consumption (Renewable Fuels Association 2008). The percentage of the US Corn crop used for ethanol production increased to 24% in 2007 (CRS 2007a). While corn prices averaged $2.15 per bushel in the 10 year period 1997-2006, corn futures prices exceeded $4.00 per bushel in November 2007. This was despite a record 2007 corn harvest of 13.1 billion bushels.

This push toward ethanol production is driven by federal incentives. Fuel blenders currently receive a $0.51 tax credit for every gallon of ethanol blended into gasoline[1]. In addition, small ethanol producers (less than 60 million gallons annually) receive $0.10 per gallon for the first 15 million gallons. These incentives have driven up production, and therefore demand for corn. As a result, the number of acres planted in corn increased 20% between 2006 and 2007, causing a 16% decrease in soybean acreage planted. Production of soybeans dropped 19% and prices doubled in 2007 (USDA 2008). This demonstrates how corn ethanol production affects food prices and production beyond corn.

In consideration of all these factors it is generally agreed that the maximum corn ethanol production in the US is between 15-16 billion gallons, or 11% of today's consumption (GAO 2008, CRS 2007a). In fact, the Energy Independence and Security Act caps out the production of corn-based biofuels in 2015 at 15 billion gallons. Further increases in ethanol production are mandated to come from "advanced biofuels", defined[2] as a "renewable fuel other than ethanol derived from corn starch...".

[1] The 2008 Farm Bill would reduce the blender's tax credit to $0.45 per gallon.
[2] Defined by the Energy Independence and Security Act, H.R. 6, Title II, page 28.

Brazil has a long and instructive history of ethanol production (Lourenco et al. 2007). Starting in 1931, the industry went through several boom and bust periods, mainly as a result of government subsidies and policies that encouraged the production and use of ethanol. In 2000, the industry took off, spurred by three factors: 1) high oil prices, 2) years of previous experience, and perhaps most importantly, 3) the mass introduction of flexible fuel vehicles (FFVs) capable of running on either ethanol or gasoline. In 2006, Brazil produced 4.5 billion gallons of ethanol from sugarcane and 75 percent of their vehicles were FFVs. In 2007, production increased to 5.02 billion gallons. Sugarcane currently occupies only two percent of total available agricultural land in Brazil, and most of it is in southeastern Brazil (far from the Amazon). There is opportunity to significantly expand its production without impacting food prices.

Ethanol produce from sugarcane is significantly less expensive than that produced from corn due to higher yields and production efficiency. Brazil exported nearly 1 million gallons in 2007, and they have the capability to export significantly higher levels of ethanol to the US. This is currently limited by the presence of a $0.54 per gallon US import duty[3]. Some feel that ethanol production could be expanded significantly in the southern hemisphere from high energy crops like sugarcane. For example, Mathews (2007) argues that is possible to supply 20 percent of the Organization for Economic Co-operation and Development (OECD) member countries' fuel demands from Southern Hemisphere biofuels production. He believes that southern hemisphere exports will grow significantly once the capacity for grain ethanol is reached in the Northern Hemisphere, and well before cellulosic ethanol becomes commercially viable.

Cellulosic Ethanol

These concerns have led some to consider producing ethanol from the ligno-cellulosic components of plant biomass. Laboratory results have shown that ethanol can be produced from a wide variety of plant materials including corn stover, straw, switchgrass and woody biomass. If this could be done commercially it would mean higher yields per acre, less intensive agricultural inputs, less competition with food crops, and a much larger potential feedstock. Ethanol made from cellulose is the same product as that made from corn -- it just requires extra steps in the process to convert the cellulose in the cell wall to sugars prior to fermentation. The problem is that the extra steps are technically challenging and prohibitively expensive relative to the cost of ethanol produced from corn starch. Therefore, even more financial incentives are required to encourage its production than in the case of ethanol produced from corn starch.

The Energy Independence and Security Act (EISA) of 2007 provides incentives through two mechanisms: mandated production levels and financial subsidies to producers. EISA 2007 mandates that starting in 2010 transportation fuels sold in the United States must (on average) contain a minimum amount of cellulosic biofuels[4]. The requirement starts at 100 million gallons and increases to 16 billion gallons in 2020. The accompanying financial subsidies operate in two ways to help ensure the goal is met. First, the law provides $500 million per year in federal grants from 2008 – 2015 to help start up new cellulosic bio-refineries. Secondly, a credit of at least $0.25 per gallon will be paid to producers if the volume of cellulosic biofuel does not

[3] The US imported 656 million gallons of ethanol from the Brazil and Caribbean countries in 2006.
[4] It is not required to be ethanol.

achieve the required minimum in any year[5]. Provisions in the 2008 Farm Bill would allow a producer's tax credit of $1.01 per gallon for cellulosic ethanol through 2012. These incentives will drive the production of cellulosic biofuels but they do not require that forest biomass will be used. Relative production economics will dictate which feedstocks make the most sense.

Nonetheless, many believe that forest residues could contribute significantly to cellulosic ethanol production. If so, this could help solve a number of problems facing forest managers today, such as reducing fuels buildup in overstocked small diameter stands, conducting ecological restoration work, and salvaging and replanting millions of acres of beetle damaged stands in the west. It could also bring much needed public attention to the importance of forests in helping meet the nation's needs. So what is the potential for cellulosic ethanol from forests?

The Economics Favor Agricultural Residues and Short Rotation Crops

The US Department of Energy states that for cellulosic ethanol production to be financially viable, three hurdles must be overcome (US Dept of Commerce 2007). First, the feedstock cost must be reduced to $30 per ton (from $60 now). Second, the yield of ethanol must be increased to 90 gallons per dry ton (from 60 gallons per dry ton now). Finally, the cost of enzymes used in the process must be reduced to $0.05 per gallon (from $0.40 now).

If these estimates are correct the feedstock cost and yield issues will be a significant challenge. First, collection and delivery costs exceed $30 per ton for the vast majority of wood that would be available in the forest. Secondly, competitive uses for industrial wood residue exceed $30 per dry ton. According to Wood Resources International (2006), the pulpwood industry paid three times more than this for clean wood chips, and five times more than this for roundwood in 2006. Therefore, it is unlikely that primary wood residues from sawmills (eg. clean chips) or roundwood would be used to produce ethanol. For other forest residues, wood pellets are a competitive product. There is a rapidly growing market for wood pellets in Europe. According to Wood Resources International, 2006 pellet prices in Sweden were $130/ton. As technology for energy production from wood residues improves, there could be significant demand in North America as well. Also the yield obtained from logging residues and small diameter wood -- which are heavy in bark content – are not expected to as high as other feedstocks.

Given that the cost of the feedstock is such a major component of the production cost of the process, it is more likely that agricultural wastes or hybrid energy crops would be used to produce the bulk of cellulosic ethanol. No matter how high the price of oil goes, whether or not forest residues are used depends on the relative production economics between forest residues and alternative feedstocks. This is an important and inescapable point. Switchgrass is a very promising agricultural crop that can be grown on marginal and eroded cropland that is unsuitable for food production. Schmer et al. (2008) conducted a bio-energy life-cycle analysis with five-year farm trials and found that switchgrass produced 540 percent more energy than was consumed in production. Greenhouse gas emissions from the resulting ethanol were found to be 94 percent lower than that estimated from gasoline. Maclaughlin et al. (2002) estimated that there are between 7.7 and 52.6 million acres of marginal and eroded cropland available for

[5] If the wholesale price of gasoline is less than $2.75 per gallon the credit paid per gallon would be equal to the difference between $3.00 and the wholesale price of gasoline.

production in the US. Further evidence of the potential for switchgrass is that the recent Chevron/Weyerhaeuser initiative is focused on switchgrass as a feedstock.

Kaylen et al. (2000) conducted an economic feasibility study for a commercial sized refinery in Missouri with energy crops, crop residues, and woody biomass all as potential sources of feedstock. Even though they assumed the same cost for both crop residues and woody biomass, they found that crop residues were the most cost effective feedstock. Therefore the optimal plant location was an agricultural area of the state.

What Can Be Learned From Investment in Cellulosic Ethanol Production

Currently there is no commercial production of cellulosic ethanol. Iogen Corporation built and operates the world's only demonstration cellulosic bio-refinery in Ottawa, Canada. Iogen has developed a specialized technology to produce ethanol from wheat straw. Goldman Sachs, Petro Canada, and Royal Dutch Shell have invested $100 million in the technology – not to build a bio-refinery, but instead to license the technology to others. It is expected that Iogen's process will be used in new bio-refineries under development.

New bio-refineries are under construction, but they are heavily subsidized by government. For example, on March 8, 2008, the Canadian Government announced a $500 million grant to Iogen to build a commercial plant in Saskatchewan to produce ethanol from wheat straw. On February 28, 2008, the Department of Energy funded six cellulosic ethanol refineries to support President Bush's Twenty in Ten Initiative.

It is instructional to note that five of the six funded plants are designed to process agricultural and landfill wastes. Included is a second Iogen plant in Idaho that will consume 700 dry tons of agricultural residues per day. Others are: Albengoa Bioenergy in Kansas (agricultural wastes), ALICO Inc. in Florida (yard, wood, and vegetative wastes), Bluefire Ethanol in Southern California (landfill waste), and Broin Companies in Iowa (agricultural wastes).

A sixth plant to receive funding is Range Fuels. It is the only plant of the six planned to process wood residues left after logging and wood based energy crops. They will use a gasification process to produce syn-gas, which will then be transformed into ethanol. This Georgia plant was the first cellulosic ethanol plant in the U.S. to break ground (November 2007). Venture capitalists provided $130 million and attracted $76 million from the DOE grant. They plan to start up a 20 million gallon per year bio-refinery using wood residues as the feedstock. The eventual track record of this plant will provide a good indication of the feasibility of processing wood residues into ethanol.

Estimates of Available Biomass

The Billion Ton Report prepared by the Department of Energy identifies the technical feasibility of producing wood for the bio-energy and bio-products industries (Perlack et al. 2005). This report identifies that up to 368 million dry tons of biomass are technically available on a sustainable basis. This amount is seven times that currently utilized.

A careful study of this report provides an estimate of how much of this technically available biomass is likely to be used to produce cellulosic ethanol. It is important to recognize that the amount that would go toward producing cellulosic ethanol depends not only on the availability of the biomass, but also on the current use of the biomass, the likely cost of delivery of the feedstock to the conversion plant, and the likely location of conversion plants. It is also important to note that this estimate does not include the potential production from short rotation woody crops, which may or may not be considered forests.

1. Diversion of industrial wastes

The Billion Ton Report estimates that there are 159 million dry tons of industrial wood by-products. However, 95 percent of this is already used for either wood and paper products (38 percent) or energy (57 percent). If the industrial wastes that are used to produce energy were instead diverted to ethanol production, it would mean the energy currently used in industrial processes would have to be replaced by other fuels. As the conversion efficiency of ethanol is much lower than that of direct-fired woody biomass, this extra conversion step could be a net loss in both economic and greenhouse gas efficiency.

It is possible that some of the mill residues that currently go to by-products like pulp, medium density fiberboard, and other panel products could be diverted to ethanol. That would depend on the relative economics driving feedstock costs. As noted above, the value of wood residues for pulp production is three times the potential value of wood biomass for ethanol in a commercially feasible bio-refinery, according to DOE estimates. Much of the unused industrial waste (5 percent) includes bark, which has little cellulose content and therefore would not have high ethanol yields.

Therefore it is unlikely that this material would be used to produce ethanol without having serious side effects that would have to be accounted for in other ways.

2. Fuel wood currently extracted from forests

The total reported biomass available also includes 35 million dry tons of biomass[6] that is currently used in residential and commercial heating, as well as in power production. If this wood were diverted to ethanol production, it would again mean that the energy loss would have to be made up in other ways, most likely with fossil fuels. Therefore it is estimated that none of this material is available to produce ethanol without having serious side effects. The lost energy would just have to be made up in other ways.

3. Wood harvested from fuel treatments

The Billion Ton Report projects that as much as 60 million dry tons of biomass could be produced from fuel treatments on overstocked stands. This would be from trees less than seven inches in diameter. Larger trees harvested at the same time would go into traditional products, which would help justify the cost of the treatment. Nonetheless, the challenges in recovering a high percentage of this volume are significant. First, the delivered cost of the small diameter biomass would have to be comparable to that of woody biomass from agro-forestry; therefore, even if handling costs could be reduced, the transportation costs for this biomass would have to be kept to a minimum. The only volume likely to be recovered would be in areas that are already close to an ethanol bio-refinery. This small diameter material would also contain a high percentage of bark, further reducing its value.

Another concern is that a cellulosic ethanol plant requires a significant amount of water. The National Renewable Energy Laboratory estimates between 1.9 and 6 gallons of water are needed

[6] Includes 16 million dry tons for future growth in this resource.

to produce each gallon of ethanol in the refining process (Aden 2007). This -- coupled with the need to minimize feedstock transport -- rules out ethanol production in areas of the interior west where water is already in short supply. Much of the fuelwood treatments that need to occur are in these arid areas.

4. Logging Residues:
The Billion Ton Report projects that 41 million dry tons of biomass are available as residues from forest operations on private lands: 32 million could be collected as logging residue and 9 million from land clearing operations. As these residues are already associated with commercially viable operations, the likelihood is higher that these residues could be collected in an economically feasible manner.

There would still be the problem of paying the cost to covert the material on site to a convenient residue for transporting, and transporting the residue to a conversion facility. This material would also contain a very high percentage of bark.

5. Urban Wastes
The Billion Ton Report projects that 36 million dry tons of biomass could be collected from urban wastes. About 17 percent of this is already used, leaving 28 million dry tons available for ethanol production. This material has the highest probability of making it into ethanol production since it must be disposed of in some manner. Therefore, much of the transportation and conversion costs are already covered.

Total Wood Biomass Available:

- 129 million dry tons is the maximum possible assuming that 100% of the available biomass from fuel treatments, logging residues and urban wastes could be economically collected and converted into ethanol.
- 64 million dry tons is available under a more conservative estimate that only 25% of the fuel treatments, 50% of logging residues, and 100% of the urban wastes could be economically collected. Even this would be a very challenging goal.

Conversion Efficiency of the Ethanol Process

The conversion efficiency of woody biomass to ethanol is dependent upon the feedstock. Laboratory yields are significantly higher for hardwoods than for softwoods.

As there are no commercial cellulosic ethanol plants in production, it is uncertain what the final yields will be. It is believed that yields in the laboratory under perfect conditions will be higher than actual results in production. The Department of Energy reports that ethanol yields are currently 60 gallons per dry ton. Their target is that yields would increase to 90 gallons per dry ton by 2012. However, much of these yield increases would most likely be due to genetic improvements in the feedstock and/or improvements in the process by concentrating on a specific type of feedstock. Forest run residues containing bark would most likely be on the low end of the yield spectrum, therefore 60 gallons per dry ton is used in this report as an estimate for future ethanol conversion yield. This is very near the theoretical maximum for softwoods obtained in the laboratory today.

Total Production

It takes 129 million dry tons at 60 gallons per dry ton to produce 7.74 billion gallons of ethanol. Since ethanol has two-thirds the BTU content of gasoline, this is equivalent to 5.16 billion gallons of gasoline. As gasoline consumption in 2006 was 142 billion gallons (DOE 2007), this is approximately 3.6 percent of today's consumption of gasoline. This should be considered a theoretical maximum. Incidentally, 7.74 billion gallons is greater than the federally mandated production level of cellulosic biofuels for the year 2018[7].

Under the more conservative assumptions in this report only 2.56 billion gallons could be produced from forests. This would be roughly 1.8 percent of today's gasoline consumption.

It is very important to keep in mind that under Title II of the Energy Independence and Security Act of 2007, ethanol produced with forest residues taken from federal lands does not qualify to meet federally mandated production levels, and would not qualify for federal price subsidies. This will undoubtedly have an impact on the quantity of forest residues used for ethanol production. Therefore, I believe that a very challenging target for cellulosic ethanol production is that two percent of today's gasoline consumption could be made from ethanol derived from existing forests.

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