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Policies to Facilitate Conversion of Millions of Acres to the Production of Biofuel Feedstock

Francis M. Epplin and Mohua Haque

First-generation grain ethanol biofuel has affected the historical excess capacity problem in U.S. agriculture. Second-generation cellulosic ethanol biofuel has had difficulty achieving cost-competitiveness. Third-generation drop-in biofuels are under development. If lignocellulosic biomass from perennial grasses becomes the feedstock of choice for second- and third-generation biorefineries, an integrated system could evolve in which a biorefinery directly manages feedstock production, harvest, storage, and delivery. Modeling was conducted to determine the potential economic benefits from an integrated system. Relatively low-cost public policies that could be implemented to facilitate economic efficiency are proposed.

Key Words: biomass, bio-oil, cellulosic, drop-in fuels, ethanol, land-lease contract, lignocellulosic, pyrolysis, switchgrass

JEL Classifications: Q16, Q18, Q15, Q42

In the absence of subsidies, carbon taxes, and mandates, it has been difficult for biofuels produced from agricultural feedstock to compete with crude oil derivatives. This article includes a discussion of U.S. energy use and use of traditional agricultural resources to produce energy feedstock. Modeling is conducted to test the economic consequences of two potential structures for producing and delivering a flow of lignocellulosic feedstock to a biorefinery. Relatively inexpensive policies that could be implemented to facilitate conversion of millions of acres of marginally productive land from current use to the production of dedicated energy crops are presented.

The United States consumes a massive quantity of energy. In 2009, the United States used an average of 18.8 million barrels of crude oil per day. Crude oil accounted for about 38 percent of U.S. energy consumption. From April 20 to July 15, 2010, the British Petroleum Deepwater Horizon Macondo Gulf of Mexico well leaked an estimated 4.9 million barrels of crude oil. The leaked oil was equivalent to 6 hours and 15 minutes of U.S. crude oil consumption.

For a number of years, public policy has been used in an attempt to bid traditional agricultural resources away from the production of food, feed, and fiber to alleviate the "excess capacity" problem in U.S. agriculture (Tweeten, 1970). In 1978, more than 26 million acres of U.S. cropland was classified as idle (Lubowski et al., 2006). Much of this idle land was diverted from crop production as a result of

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Francis M. Epplin is the Charles A. Breedlove professor, Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma. Mohua Haque is a postdoctoral fellow, The Samuel Roberts Noble Foundation, Ardmore, Oklahoma.

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various federal programs. As Hanson noted in 1985, "...Recognition of the increasing prospect of current excess capacity in U.S. agriculture provides an additional reason for agricultural economists to reconsider the potential of ethanol production as a strategy to improve farm incomes and lower agricultural surpluses...." (Hanson, 1985, p. 74). One consequence of the grain ethanol programs is that approximately 20 million acres of some of the nation's most productive land has been diverted from the production of food, feed, and fiber. Herndon posited that "...corn-based ethanol production and its policy-induced tax incentives and tariff protection . . . have created a revolution in U.S. agriculture...." (Herndon, 2008, p. 413).

Grain Ethanol

Texas oilman T. Boone Pickens argues that most policymakers have understood that the grain ethanol program has been about agriculture and not about energy. He reported that Senator Bob Dole of Kansas told him in 1988 "...Boone, you're going around the Hill up here telling people that ethanol is not really a good fuel.... You need to understand that everybody up here understands what you tell them..., there are 21 farm states and that's 42 senators, and they want to subsidize corn, ...they're going to subsidize corn ...You're wasting their time and your time both. They are going to subsidize ethanol, and that's it...." (Frontline, 2008).

Although the policies have had a major impact on the excess capacity problem in agriculture, the policies have been less successful in fulfilling the energy goals included in President Nixon's 1974 state of the union address where he stated, "...Let this be our national goal: At the end of this decade, ..., the United States will not be dependent on any other country for the energy we need to provide our jobs, to heat our homes, and to keep our transportation moving...." (Nixon, 1974). U.S. net imports of crude oil and petroleum products increased from 2.15 billion barrels in 1974 to 3.53 billion barrels in 2009. A reasonable conclusion is that President Nixon's stated goal to not be dependent on other countries for energy has not been fulfilled.

In 2009, 10.6 billion gallons of ethanol were produced from grain in the United States. The gross energy in the ethanol was equivalent to the energy contained in 7 days and 9 hours of U.S. crude oil use. If the entire grain output from the 2010 U.S. corn crop of 12.66 billion bushels were converted to ethanol, it would contain gross energy equivalent to 24 days (6.7%) of U.S. crude oil use. Given that a substantial quantity of crude oil is required to power the tractors, combines, trucks, and trains used to produce and distribute the grain ethanol, arguing that the grain ethanol program has had much of an impact on crude oil use is difficult. Another reasonable conclusion is that the grain ethanol policies, although successful in addressing the "excess capacity problem in agriculture," have not contributed a great deal toward achieving President Nixon's stated energy independence goal. Because of land resource constraints, grain ethanol's potential contribution toward U.S. energy independence is limited.

Cellulosic Ethanol

Converting cellulose to ethanol is not new. In 1910, the Standard Alcohol Company built a cellulosic ethanol plant in South Carolina to process waste wood from a lumber mill. The plant was operated until after World War I (Sherrard and Kressman, 1945). In the 1940s, the U.S. government funded a cellulosic ethanol plant as an insurance plant in case of grain shortage. Economics was a secondary consideration during wartime. When the wars and subsidies ended, the plants were not economically viable. However, interest in improving cellulosic ethanol production efficiency did not die. For example, Tyner wrote in 1980 that "...By the mid 1980s, most authorities believe that cellulose conversion technologies will be commercially available to produce ethanol from crop residues, forage crops, wood, or municipal solid waste...." (Tyner, 1980, p. 961).

Development of energy crops such as switchgrass was envisioned as a way to convert low-quality land to more productive use and, at the same time, reduce the cost of government commodity and conservation programs that were funded to entice landowners to set aside the land from the production of traditional crops (the "excess capacity" problem). "...The rationale for developing lignocellulosic crops for energy is that...poorer quality land can be used for these crops, thereby avoiding competition with food production on better quality land...." (McLaughlin et al., 1999, p. 293). According to Perlack et al. (2005), more than 50 million U.S. acres of low-quality land could be converted for biomass production with minimal effects on food, feed, and fiber production. They also estimate that more than a billion tons of lignocellulosic feedstock such as corn stover, wheat straw, and switchgrass could be produced annually in the United States (Perlack et al., 2005).

In a frequently referenced *Science* article, Lynd et al. (1991) hypothesize that given continued investment in research, by the year 2000, technology would be developed enabling the production of cellulosic ethanol for a wholesale selling price of $0.60 per gallon ($0.96 in 2010 dollars)...." President Bush's 2006 state of the union speech included: "...we have a serious problem, America is addicted to oil...." "...We'll...fund...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...." (Bush, 2006). In 2006, Pacheco (2006) reported to a U.S. Senate committee that "...Our goal is to reduce the cost of producing cellulosic ethanol from $2.25 a gallon in 2005, to $1.07 in 2012...."

In anticipation of an economically viable feedstock production and conversion system, the U.S. Energy Independence and Security Act (EISA) of 2007 included a provision to mandate that by 2022, if produced, 16 billion gallons of cellulosic biofuels, primarily cellulosic ethanol, be used. The mandate for grain ethanol use was capped at 15 billion gallons. Biomass from dedicated energy crops such as switchgrass and crop residues was expected to provide most of the feedstock requirements to fulfill the EISA cellulosic biofuels goal. Kenkel and Holcomb (2009) noted that the mandates did not address a number of critical issues, including how the mandated production would be financed.

Original mandated EISA targets for cellulosic ethanol were 100 million gallons in 2010 and 250 million gallons in 2011(U.S. Environmental Protection Agency, 2010). The U.S. Environmental Protection Agency (EPA) is required to set the standard each November for the next year based on the volume projected to be available. The 2010 mandate was reduced from 100 to 6.5 million gallons and the 2011 mandate has been reduced from 250 to 6.6 million gallons (U.S. Federal Register, 2010). Although the market for cellulosic ethanol was mandated, it has not been produced at the mandated levels, suggesting a potential problem with the economics.

Kazi et al. (2010) evaluated the economics of producing ethanol from corn stover and concluded that the cost of the most economical of the eight conversion processes evaluated would be $5.13 per gallon of gasoline equivalent. A regression of the annual price of gasoline (U.S. Energy Information Administration, 2010a) on the price of crude oil (U.S. Energy Information Administration, 2010b) (1989–2009) results in the following equation: gasoline ($ per gallon) $= 0.05 + 0.0259 \times$ crude oil price ($ per barrel). By this measure, the most economical cellulosic ethanol system as computed by Kazi et al. (2010) would be competitive with crude oil priced at $196 per barrel. The average annual spot price for crude oil ranged from $26 (2001) to $100 (2008) per barrel over the decade from 2000–2009. In the absence of subsidies and mandates, a substantial increase in the price of crude oil would be required for the processes considered by Kazi et al. (2010) to produce economically competitive cellulosic ethanol.

The vast majority of fuel ethanol produced in the United States is sold as E10 (a 10% blend of ethanol with 90% gasoline). Most gasoline-powered vehicles currently in use in the United States are warranted for ethanol levels not exceeding E10 (except for flex-fuel vehicles). In 2010, the U.S. EPA announced permission to use E15 in vehicle models 2007 and newer. In January of 2011, the EPA ruled that E15 could also be used in model year 2001 through 2006 cars, SUVs, and light trucks. In 2009, the United States consumed 138 billion gallons of gasoline that contained approximately 10 billion gallons of ethanol. The 2015 EISA grain ethanol mandate is for 15 billion gallons. Use of 15 billion gallons would require a number of flex-fuel vehicles that can use E85 blends. However, Tyner argued before the EPA rulings permitting E15, that the "... numbers (of flex-fuel vehicles) cannot grow fast enough to matter much in the next five years. ... Second generation ethanol ... is dead on arrival. ... Corn ethanol is cheaper and will completely fill the blend limit. That is one reason there is more talk about non-ethanol second generation biofuels..." (Tyner, 2009). Tyner's assertion is consistent with that of Wetzstein (2010) who concluded that "...cellulosic ethanol will always be the technology of the future. Even with government incentives and regulations, cellulosic-based ethanol has major economic and technical hurdles to overcome before it can be competitive with corn-based ethanol..." (Wetzstein, 2010, p. 396).

Ethanol is not an ideal liquid fuel substitute in a country with an infrastructure and vehicles designed to use gasoline, diesel, and jet fuel. Ethanol contains less energy (75,700 btu) per gallon than unleaded gasoline (115,000 btu) (U.S. Department of Energy, 2009). When ethanol is blended with gasoline at levels of 10% or less, it has value as an oxygenate in addition to its energy value. However, when used in greater proportions in engines with compression ratios designed for unleaded gasoline, the lower btu content results in proportionately lower mileage. Because it mixes with water, ethanol, or gasoline containing ethanol, it cannot be moved practically through the U.S. pipeline system. Ethanol requires splash blending and separate handling. Ethanol has a higher vapor pressure, which results in additional management issues to fulfill environmental regulations. Another limitation is that ethanol cannot be used as a direct substitute for diesel fuel and jet fuel.

Drop-In Biofuels

For a number of years, efforts have been underway to develop economically viable "drop-in" alternatives to petroleum. The ideal drop-in would be invisible to the operator, meet fuel performance requirements of existing engines, require no change to the current stock of engines, be mixed or alternated with petroleum fuels, and require no change to the infrastructure (Tindal, 2010). For commercial application and to attract private investment, an additional critical attribute is that the alternative be economically competitive. One potential process candidate is conversion of lignocellulosic biomass with fast pyrolysis (in which biomass feedstock is heated in the absence of oxygen) to produce bio-oil that may be upgraded to produce hydrocarbon fuels (Crossley et al., 2009; Regalbuto, 2009; Schirmer et al., 2010; Wright et al., 2010).

Wright et al. (2010) evaluated the economics of fast pyrolysis of corn stover to bio-oil with upgrading of the bio-oil to naphtha and diesel range fuels. They estimate that a pioneer (first of a kind) plant could produce at $3.41 per gallon of gasoline equivalent, and that an n^{th} optimized plant could produce at a cost of $2.11 per gallon of gasoline equivalent, roughly equivalent to a crude oil price of $80 per barrel. By this measure, the budgeted system to produce naphtha and diesel range fuels from upgraded fast pyrolysis bio-oil is more promising than the most economical cellulosic ethanol system as budgeted by Kazi et al. (2010) that has an estimated cost of $5.13 per gallon gasoline equivalent.

Two things remain to be determined: whether any technology will be forthcoming in the near future to convert biomass into a biofuel that can compete economically with crude oil and whether the mandates for cellulosic biofuels in the 2007 EISA will continue to be relaxed. However, the agricultural research community could contribute by designing cost-efficient feedstock production and delivery systems.

An Alternative Use for Lower-Quality Lands

For a conversion rate of 80 gallons per ton, the mandate of 16 billion gallons per year of cellulosic biofuels (by 2022) would require 200 million tons of biomass. If a perennial grass such as switchgrass or miscanthus was the single source of feedstock, for an annual yield of three dry tons per acre, a total of 67 million acres would be required. For a yield of seven tons per acre, 29 million acres would be required. In 2010, U.S. farmers planted 88 million acres of corn, 78 million acres of soybeans, 54 million acres of wheat, and 11 million acres of cotton (U.S. Department of Agriculture, National Agricultural Statistics Service, 2010). Landowners had 30 million acres enrolled in the Conservation Reserve Program (U.S. Department of Agriculture, Farm Service Agency, 2010). If an economically competitive business model is developed, the potential impact of a lignocellulosic biomass biofuels program on the use of U.S. agricultural lands is quite substantial. The cellulosic biofuels mandates could provide an alternative use for millions of acres of poorer quality cropland and cropland used for pasture or grazing.

Investors in a cellulosic biofuels biorefinery will expect the business plan to contain reasonable plans for feedstock procurement. Optimal cellulosic biorefinery size is unknown. However, both Kazi et al. (2010) and Wright et al. (2010) budgeted for 2,205 dry tons per day (772,000 tons per year). For an average yield of three dry tons per acre, a total of 257,000 acres would be required per biorefinery. If an average yield of 7 tons per acre could be achieved, only 110,000 acres would be required per biorefinery. Policies to enable efficient land acquisition, feedstock production, harvest, storage, transportation, and delivery could contribute to economic viability.

A number of discussions have occurred regarding what has become to be known as the "chicken and egg" problem with a dedicated energy crop such as switchgrass or miscanthus and cellulosic biorefineries. That is, a rational landowner would not establish a perennial grass for intended use as feedstock until a biorefinery is built and long-term contracts are offered. However, rational investors would be reluctant to invest in a biorefinery that did not have a reasonably certain supply of feedstock for the life of the plant. Progress has been made toward the development of the production and harvest of dedicated energy crops such as switchgrass and miscanthus. However, the structure of a mature switchgrass feedstock-based cellulosic biorefinery system is not likely to resemble the atomistic structure that we observe for U.S. grain production and consequently is not likely to resemble the corn-based ethanol system. A corn ethanol biorefinery may simply post a price and have feedstock delivered by the existing grain marketing infrastructure. No such infrastructure exists for perennial grasses.

Atomistic vs. Integrated Structure

An atomistic structure could evolve in which the biorefinery could enter into long-term production and harvest contracts with individual farmers (Epplin et al., 2007; Larson, English, and He, 2008). Over time, a spot market might develop. Alternatively, the biorefinery could engage in long-term land-lease contracts before, or simultaneously with, construction of a biorefinery. An integrated system could evolve in which the biorefinery directly manages feedstock production, harvest, storage, and delivery.

A number of studies have reported estimates of switchgrass production, harvest, storage, and transportation cost (Epplin, 1996; Duffy, 2007; Brechbill and Tyner, 2008; Khanna, Dhungana, and Brown, 2008; Mooney et al., 2008; Perrin et al., 2008; Sokhansanj et al., 2009). Most of these studies budgeted switchgrass production costs as if it were a traditional crop with an atomistic structure. Switchgrass is assumed to be harvested during a narrow timeframe after maturity when maximum dry matter yield can be achieved (Kering et al., 2009). This system would result in maximum harvested yield per acre but not necessarily in the most efficient system for delivering a flow of biomass to a biorefinery throughout the year.

In the Southern Plains of Oklahoma, the switchgrass harvest window could extend from July through March. Biomass yield is lower from stands harvested in midseason and protein (nitrogen) levels are relatively high in grasses cut in midseason (Haque, Epplin, and Taliaferro, 2009). Late in the growing season, nitrogen translocates from the above-ground foliage to the plant's crown and rhizomes. If harvest is delayed until after the first frost and the initiation of senescence, biomass yield will be maximized and nitrogen will have translocated, which reduces the quantity of nitrogen fertilizer needed for biomass production in subsequent years (Madakadze et al., 1999; Sanderson, Read, and Reed, 1999; Reynolds, Walker, and Kirchner, 2000; Vogel et al., 2002; Adler et al., 2006; Kering et al., 2009).

An extended harvest season could reduce the required investment in harvest machinery, result in a lower average harvestable yield per acre, and would require more nitrogen fertilizer, less land for storage, and more land for growing switchgrass. However, because harvestable yield and optimal fertilizer levels differ across harvest month, an extended harvest system would be difficult to implement with an atomistic structure. Modeling could be conducted to determine if economic benefits would be forthcoming from an extended harvest season that may be implemented more easily with an integrated structure vs. a narrow harvest season likely to evolve with an atomistic structure.

A model was constructed and solved to determine the cost to deliver a flow of 2,000 dry tons per day of switchgrass to a biorefinery optimally located in Oklahoma for both a 2-month and a 9-month harvest window. The 2-month harvest window is a proxy for an atomistic structure, and the 9-month harvest window is a proxy for an integrated structure. The 9-month harvest season extends from July through March. The model accounts for differences in yield and nitrogen fertilizer requirements across harvest months. Harvest is restricted to September and October for the 2-month system.

Modeling Proxies for Atomistic and Integrated Structures

A mathematical programming model similar to those described by Tembo, Epplin, and Huhnke (2003), Epplin, Mapemba, and Tembo (2005), Mapemba et al. (2007), and Mapemba et al. (2008) was formulated to determine the cost to deliver a flow of switchgrass biomass to a 2,000-tons-per-day biorefinery. The model simultaneously determines the optimal biorefinery location; the area and quantity of switchgrass harvested by county, by month, and by land category; the optimal number of harvest machines; and storage and transportation requirements to deliver a flow of switchgrass biomass to the biorefinery.

The model includes 57 Oklahoma counties as production regions. Switchgrass biomass yield estimates for each of 57 counties for each of 9 harvest months were synthesized from several sources (Graham, Allison, and Becker, 1996; Fuentes and Taliaferro, 2002; Haque, Epplin, and Taliaferro, 2009). Table 1 includes estimates of the proportion of switchgrass expected yield by harvest month. Harvest during April, May, or June in the region is not modeled because harvest during these months may damage plant growth for subsequent years. Maximum expected yield is obtained by harvesting in either September or October. The expected yield from harvest in July is 80% of maximum. If switchgrass is left to stand in the field, dry matter losses of 5% per month are expected from November through March (Vogel et al., 2002).

Table 1 also includes estimates of the level of nitrogen (pounds per acre) applied in the spring required to achieve plateau yield by

Table 1. Switchgrass Yield and Nitrogen Requirements by Month of Harvest

January	February	March	April	May	June	July	August	September	October	November	December
Proportion of Potential Switchgrass Yield by Harvest Month											
0.80	0.75	0.70	0	0	0	0.79	0.86	1.00	1.00	0.90	0.85
Level of Nitrogen (pounds per acre) by Harvest Month											
63	63	63	0	0	0	80	74	69	63	63	63

Source: Haque, 2010.

harvest month. For modeling purposes, the price of nitrogen relative to the price of switchgrass is assumed to be optimal at the plateau point on the production surface. Fields that are harvested in July are expected to require 80 pounds per acre of nitrogen to achieve the plateau yield, whereas fields harvested during and between October and March are expected to require only 58 pounds per acre. Another assumption is that fields harvested during and between July and September are expected to require 10 pounds of P_2O_5 per acre per year (Thomason et al., 2004).

Switchgrass production is restricted to two land classes: cropland and improved pasture land. Data from the Census of Agriculture were used to determine acres of cropland and improved pasture (U.S. Department of Agriculture, 2002). Restrictions are included in the model to limit switchgrass production in each county to no more than 10% of the county's cropland and no more than 10% of the county's improved pasture land. Another assumption is that the use of this cropland and improved pasture land can be acquired at a long-term lease rate of $60 and $40 per acre per year, respectively. The average 2005–2009 cropland cash rental for Oklahoma nonirrigated cropland ranged from $28 to $31 per acre, and the average 2005–2009 pasture land cash rental for Oklahoma ranged from $8.50 to $10.50 per acre (U.S. Department of Agriculture, National Agricultural Statistics Service, 2009). The assumptions of $60 and $40 per acre for cropland and pasture land-lease rates are made to account for the need to entice landowners to enter into a long-term lease that would be necessary for the perennial grass and to recognize that land-lease rates in the vicinity of a biorefinery would increase in response to the plant's existence. The biorefinery is assumed to operate 350 days per year and require 2,000 dry tons of feedstock per operating day.

Biomass harvest and field storage would require machines that could mow, rake, and bale feedstock and require a machine that could collect, transport, and stack bales. The integrated harvest unit concept introduced by Thorsell et al. (2004) and modified by Hwang (2007) was revised and used to determine the cost of switchgrass harvest machines. Expert opinion (American Society of Agricultural and Biological Engineers, 2006; AGCO Corporation, 2010; Lazarus and Smale, 2010; Stinger, 2010) was used to determine the specific windrower, rake, baler, and stacker to be budgeted. The budgeted cutting unit consists of a self-propelled windrower (190 hp) equipped with a 16-foot rotary header and a laborer. A raking–baling–stacking harvest unit consists of three wheel rakes, three 55-horsepower tractors, three balers, three 200-horsepower tractors, a field transporter, and seven laborers.

The annual ownership and operating cost of a cutting unit for a 9-month harvest season is estimated to be $106,463. This value includes ownership costs (depreciation, interest on average investment, taxes, insurance) and operating costs (fuel, oil, repairs, and lubricants) for a windrower equipped with a rotary header and the cost of labor. If the unit is used for 2 months per year, the annual ownership and operating cost of the cutting unit is estimated to be $31,263. The annual ownership and the operating cost of a raking–baling–stacking harvest unit for a 9-month harvest season is estimated to be $545,516. If the unit is only used for 2 months, the annual ownership and operating cost is estimated to be $169,866.

For safe baling in large rectangular solid bales, a moisture content of no more than 15% is recommended. In most months, the number of days that switchgrass may be safely baled is less than the number of days that standing switchgrass may be cut. In addition, harvest days for baling and cutting differ across counties because harvest operations are heavily weather-dependent. The number of days available for cutting and baling in each month for each of the 57 Oklahoma counties (based on various weather variables and historical weather data) were obtained from Hwang et al. (2009). An integer variable is included to determine the optimal number of cutting units (windrowers) and another integer variable to determine the optimal number of harvest units (rakes, balers, tractors, and stackers). Candidate biorefinery locations are included in the model as binary variables. Additional details regarding the model including estimates of transportation and storage costs can be found in Haque (2010).

Model Results

Table 2 includes a summary of results of estimated costs, number of harvest units, harvested acres, and tons harvested to provide a flow of switchgrass feedstock to a biorefinery for the two models. Restricting harvest to two months increases the costs of delivering feedstock by approximately $12 per ton over the costs for the 9-month harvest system. The estimated costs for land rent, establishment, maintenance, harvest, storage, and transportation for the 9-month harvest window are $52 per ton vs. $64 for the 2-month window (Table 2; Figure 1). Most of this cost difference can be attributed to the difference in harvest costs, which are estimated to be $15 per ton more for the 2-month harvest system.

The 2-month system requires substantially more harvest machines which increases machinery ownership costs. The optimal number of harvest units for cutting increases from 18 for the 9-month harvest window to 96 for the 2-month harvest window. The optimal number of raking–baling–stacking harvest units increases from 14 for the 9-month harvest window to 100 for the 2-month harvest window. The increase in harvest machines is not proportional because the months do not contain the same number of harvest days, and the number of hours available for harvest differs across month (Hwang et al., 2009).

The 2,000-tons-per-day biorefinery requires 700,000 tons per year (assuming 350 days of operation per year). Total biomass harvested for the 9-month and 2-month systems is 710,649 and 737,918 tons, respectively (Table 2). More biomass is harvested for the 2-month season to compensate for the additional storage losses, which are modeled as a function of the time in storage. Hence, the harvested tons requirement is greater for the 2-month harvest system than for the 9-month harvest system. For a 9-month harvest system, only 71,400 tons and 32,592 tons

Table 2. Comparison of Results of Two Models for Estimated Costs, Number of Harvest Units, Harvested Acres, and Tons Harvested to Provide a Flow of Switchgrass Feedstock to a 2,000-Dry-Tons-per-Day Biorefinery

	Model Comparison	
Category	Integrated Structure (9-month harvest season)	Atomistic Structure (2-month harvest season)
Land rent ($/ton)	9.29	7.97
Establishment and maintenance cost ($/ton)	6.16	5.24
Cost of nitrogen ($/ton)	6.38	5.42
Cost of phosphorus ($/ton)	0.39	
Total field cost ($/ton)	12.92	10.66
Harvest cost ($/ton)	13.65	28.55
Field storage cost ($/ton)	0.41	1.66
Transportation cost ($/ton)	16.02	15.47
Total cost of delivered feedstock ($/ton)	52.29	64.30
Harvest units for cutting (no.)	18	96
Harvest units for baling (no.)	14	100
Biomass harvested from cropland (tons)	197,795	208,820
Biomass harvested from improved pasture land (tons)	512,853	529,098
Total biomass harvested (dry tons)	710,649	737,918
Cropland harvested (acres)	36,592	33,672
Improved pasture land harvested (acres)	107,616	88,905
Total land harvested (acres)	144,208	122,577

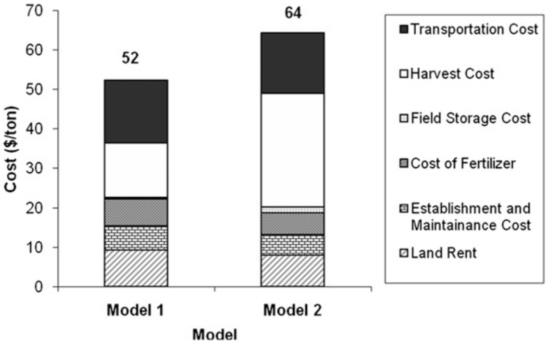

Figure 1. Estimated Costs ($/ton) to Provide a Flow of Switchgrass Feedstock to a 2,000-Dry-Tons-per-Day Biorefinery for both 9-Month (integrated structure proxy, Model 1) and 2-Month (atomistic structure proxy, Model 2) Harvest Windows

are scheduled for harvest in September and October, respectively. However, when the harvest window is restricted to September and October, 509,166 and 228,752 tons are scheduled for harvest in September and October, respectively. The chart in Figure 2 illustrates the number of tons harvested per month for both systems.

One disadvantage of a 9-month harvest season is that the harvestable yield per acre declines if harvest is extended beyond October. As a result, fewer acres are required for the 2-month harvest system (122,577) than for the 9-month harvest system (144,208). The model enables a holistic comparison of the economic tradeoffs between the increased harvestable yield per acre from the 2-month harvest system vs. the rather substantial decrease in harvest costs per ton for the 9-month system. Leasing an additional 21,600 acres and establishing switchgrass on it is more economical than investing in and maintaining an additional 78 windrowers and 86 raking–baling–stacking harvest units (258 more rakes, 258 more 55-horsepower tractors, 258 more balers, 258 more 200-horsepower tractors, 86 more stackers). Details of the economic tradeoffs are provided in Table 2. The 9-month harvest season optimally requires more acres, which results in greater land rent, establishment and maintenance costs, and fertilizer cost per ton of delivered switchgrass. However, these costs are substantially less than the additional harvest and storage costs of the 2-month harvest system.

Based on the assumptions included in the model that consider many of the tradeoffs encountered when the length of the harvest window is changed, the strategy of extending harvest over many months is economically preferable to a strategy of harvesting only in peak yield harvest months. Results confirm that, as expected, nitrogen and land requirements are greater, but harvest machinery investment requirements are lower for an extended harvest season strategy (9-month harvest season) than a restricted harvest window (2-month harvest season). Based on the model results, a 2-month harvest season would increase the cost to deliver feedstock by 23 percent.

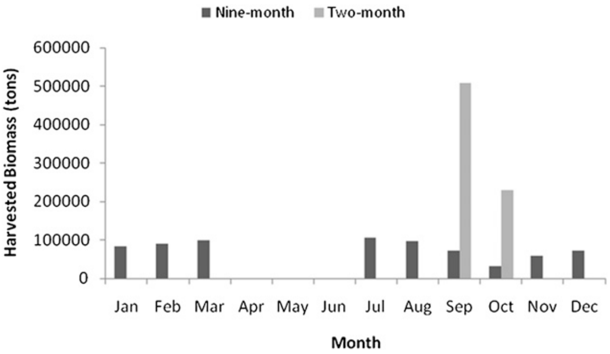

Figure 2. Switchgrass Harvested per Month for 9-Month (integrated structure proxy) and 2-Month (atomistic structure proxy) Harvest Systems to Provide a Flow of Feedstock to a 2,000-Dry-Tons-per-Day Biorefinery

This finding illustrates that the harvest window matters and it also suggests that a wide harvest window under a land-lease integrated structure would be economically preferable to a narrow harvest window and atomistic structure. Results from the model also show that given the investment required in harvest machines and the need to provide a continuous flow of biomass throughout the year, an efficient business plan built on the use of a perennial grass feedstock such as switchgrass would include a highly coordinated harvest, storage, and delivery system with harvest extended over as many months as permitted by species and weather.

Policies to Enable an Economically Efficient System

Results of the model suggest that (in the absence of government imposed distortions) a cost-efficient switchgrass feedstock biorefinery system could engage in long-term contracts with landowners to lease a sufficient quantity of land to provide for feedstock needs before, or simultaneously with, construction of a biorefinery.

Switchgrass production in postestablishment years does not require many activities: only one trip per year for fertilizer followed by a single harvest per year. Cropland and improved pasture land could be converted from current use to cellulosic biomass feedstock production in a manner similar to what occurred when millions of acres were converted from cropland and enrolled in the Conservation Reserve Program (CRP). The difference is that the biorefinery rather than the government would be the lessee and would be responsible for paying the leasing cost.

The CRP was established in 1985. The U.S. Department of Agriculture (USDA) provided CRP participants with an annual per-acre rent and half the cost of establishing a permanent land cover (usually grass or trees) in exchange for 10- or 15-year leases. During the first three enrollment periods in March, May, and August of 1986, more than 8 million acres were contracted. An additional 13.9 million acres were contracted in February and July of 1987. Within 2 years after the 1985 legislation, more than 22 million acres were under contract (Osborn, Llacuna, and Linsenbigler, 1995). This suggests that if an economically competitive biorefinery technology is developed, entrepreneurs could prepare a field-to-fuel business model and contract and convert millions of acres from current use to the production of dedicated energy crops in a relatively short period of time.

Companies may be reluctant to lease sufficient quantities of land to provide for feedstock needs and/or the public or elected representatives may place impediments limiting their ability to do so. One example is the current harvest month restrictions placed on the harvest of biomass from CRP lands. Ambiguities as to what determines feedstock quality and how to provide a flow of feedstock throughout the year are likely to be resolved much more quickly if the annual payment to the landowner is set. Leased land would enable the biorefinery to manage feedstock quality and harvest to optimize the field to biofuel process.

Public policy could be modified to enable companies to subcontract existing CRP acres from the USDA subject to approval from landowners. Policies that restrict harvest timing could be relaxed. The USDA could maintain the contract and continue to make rental payments to the landowners. Policies could be adjusted to enable companies to either use existing species or to establish other species on the land. The companies would be responsible for activities, including harvest, and for reimbursing the USDA for the rental fees.

CRP-type contracts could be made directly between the companies and landowners. Public policy could facilitate these contracts by enabling the use of the USDA Farm Service Agency and USDA Natural Resources and Conservation Service infrastructures to identify suitable acres for contract. Because landowners may be skeptical of contracting with a startup (given the history of ethanol business bankruptcies), additional policies could be implemented to enable the USDA to provide an insurance mechanism to facilitate contract insurance. Experts from the USDA's Risk Management Agency could contribute to designing insurance to mitigate moral hazard issues.

Conclusions

Grain ethanol public policies have had a major impact on what has historically been described as the excess capacity problem in U.S. agriculture. The policies have been less successful in fulfilling the often stated goal of energy independence. Projected cost targets for cellulosic ethanol have not been met, and cellulosic ethanol may well be "dead on arrival." Projected cost estimates for advanced "drop-in" fuels are promising. However, it remains to be determined if these estimates are on target or if they are overly optimistic.

The modeling exercise conducted for this article was predicated on the following assumptions: 1) an economically competitive technology for converting lignocellulosic biomass to some type of biofuel (if not cellulosic ethanol, perhaps a drop-in fuel) will be forthcoming; 2) a biorefinery will require a flow of feedstock throughout the year; 3) for some situations and in some regions, the most economical feedstock will be a dedicated perennial species such as switchgrass or miscanthus; 4) in the Southern Plains of Oklahoma, the switchgrass harvest window extends from July through March; 5) expected switchgrass biomass yield and fertilizer requirements differ by harvest month; 6) landowners would be reluctant to establish a perennial grass for intended use as feedstock until a long-term contract is signed; 7) investors would be reluctant to invest in a biorefinery that did not have a reasonably certain supply of feedstock for the life of the plant; and 8) contracts based on yield would be more costly to execute than contracts for acres.

Based on these and other assumptions incorporated into the model, a wide harvest window under a land-lease integrated structure would be economically more efficient than a narrow harvest window and atomistic structure. Given the investment required in harvest machines and the need to provide a continuous flow of biomass throughout the year, an efficient business plan built on the use of switchgrass could be expected to include a highly coordinated harvest, storage, and delivery system with harvest extended over as many months as permitted by weather.

Because average deliverable yield per acre would be lower for an extended harvest season, it would require more land and more fertilizer. However, the reduction in harvest and storage cost would more than offset the additional cost for land and fertilizer. The estimated cost to deliver a flow of feedstock is approximately 20% less for an integrated structure. In addition, although not estimated, transaction costs to procure feedstock are likely to be lower for an integrated structure.

Several inexpensive public policies could be implemented to facilitate the conversion of millions of acres from current use to the production of perennial grasses: 1) enable the use of existing CRP land identification and leasing infrastructure to facilitate contracting; 2) enable biorefineries to contract with the government to purchase Farm Service Agency and the Natural Resources Conservation Service (NRCS) services to assist the biorefinery in identifying and leasing acres from landowners; 3) relax the harvest restrictions on existing CRP acres and enable biorefineries to subcontract (with landowner approval) for current CRP acres; and 4) enable the USDA Risk Management Agency to design lease insurance to protect land owners who have invested in the establishment of perennial species from biorefinery breach of contract.

Given the potential efficiencies from coordinated harvest, storage, and delivery, if an economically viable system for converting biomass from dedicated perennial species to biofuels is developed, market forces are likely to drive the system toward vertical integration. The structure of the industry may not resemble that of the atomistic U.S. grain production system.

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