Cellulosic Ethanol / Bioethanol in Kansas

Dr. Richard Nelson, Kansas State University Engineering Extension

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Introduction

Recent trends in energy prices have prompted concerns about the U.S. energy supply, especially with respect to petroleum-based liquid fuels. Research, development, and policy efforts are underway to substantially increase the use of renewable energy in the U.S. and, as such, interest has arisen lately in producing bioethanol from a variety of cellulosic feedstocks, namely herbaceous energy crops (switchgrass, big bluestem) and agricultural crop residues (corn stover and wheat straw). The Energy Policy Act of 2005 defines cellulosic matter as that which is available on a renewable or recurring basis and includes dedicated energy crops and agricultural crop residues. (Although other sources, such as wood wastes and municipal solid wastes, are included, their contribution as a cellulosic feedstock is relatively minor.) Production of cellulosic ethanol has potential to offset some of the concerns this nation faces related to energy security, the environment, and the economy.

The Energy Policy Act of 2005 (H.R. 6), signed into law in August 2005, contains a number of incentives designed to spur production of ethanol from cellulose (Renewable Fuels Association, 2005). Specifically, the Act authorizes:

- a credit-trading program where 1 gallon of cellulosic biomass ethanol or waste-derived ethanol is equal to 2.5 gallons of renewable fuel,
- a cellulosic biomass program of 250 million gallons in 2013,
- a loan guarantee program of $250 million per facility,
- a $650 million grant program for cellulosic ethanol,
- an advanced biofuels technologies program of $550 million,
- support for biomass research and development, and
- a program of production incentives to deliver the first billion gallons of annual cellulosic ethanol production.

Production of energy crops and/or utilization of crop residues for bioethanol feedstock raise issues associated with land-base sustainability and water. In addition, farmers and landowners may be reluctant to change from current agricultural practices to alternative fuel/energy production. The manner in which these lands are utilized and managed for bioenergy production is extremely critical in assessing the total energy and environmental life-cycle sustainability of bio-based renewable fuels.

Switchgrass has been produced and adequately demonstrated on a relatively small scale as a co-firing fuel with coal at large electric generating facilities, but it is not currently produced on a large-scale (GW of electricity or billion gallons per year) in the U.S. (Chariton Valley Resource Conservation and Development, 2003). In addition, large-scale production will more than likely require it to compete with existing uses for agricultural land, namely commodity crop production.

Agricultural crop residues are generally seen as a “waste” product that must be dealt with in conventional agriculture operations primarily through field maintenance (tillage), but their removal presents sustainability concerns, most notably soil erosion and loss of soil tilth and soil moisture. The potential use of agricultural crop residues must be evaluated at the county and soil type level.

Analytical models have indicated switchgrass exhibits significant production (total tons) potential in Kansas from an agronomic standpoint, but the profitability of energy crops relative to the alternative uses for land will be a prime determinant of the quantities of these feedstocks that can potentially be available for bioenergy uses. Herbaceous energy crop production offers tremendous environmental benefits with reductions in soil erosion of greater then 90% versus conventional commodity crop production which can potentially translate into improved water quality for rural communities, especially on marginal lands (Nelson, Ascough, and Langemeier, 2006). In addition, herbaceous energy crop production can increase soil carbon which could also have an impact on climate change.

Switchgrass Overview

Crops grown specifically for energy use—dedicated energy crops—are expected to become a major biomass resource for use in the electrical and transportation sectors. The dedicated energy crop receiving the greatest attention in the U.S. for bioethanol production is switchgrass.

Switchgrass is a perennial and needs planting only once during a multi-year period, requires no field maintenance (tillage) except before establishment and minimal chemical applications after establishment, which enhances its energy-profit ratio. Switchgrass has a deep root system—the below-ground biomass is as great as the above-ground biomass. This large and deep root system, combined with fine root turnover, makes switchgrass an excellent crop for erosion control and for addition of organic matter to depleted soils.

A recent economic study examined the commercial potential to produce switchgrass throughout the U.S and estimated 293 million dry tons of switchgrass could potentially be supplied at a price of $50/dry ton or less by the year 2025 (Table 1) (Walsh, 2006, unpublished manuscript). The study used a dynamic model of the U.S. agricultural sector (POLYSYS) that shifts cropland acres from current uses to switchgrass production based on relative profits and assumed expected 2005 regional harvest yields (cropland acres, rainfed conditions) from 2 to 6.5 dry tons/acre. However, the analysis was not detailed at the county or, more importantly, the sub-county level; used average yields across agricultural statistic districts/crop reporting districts; and employed general planting and harvesting machinery sets. Yields and estimated production costs vary substantially across counties and definitely by soil type within a county. Cost per ton of crop harvested is also sensitive to the yield and machinery compliment used for production and harvest. A similar, but more detailed (county level) analysis for the state of Kansas has not been performed.

Table 1. Estimated switchgrass supply (million dry tons) at select prices.

Year	$20/dry ton	$30/ dry ton	$40/ dry ton	$50/ dry ton	$60/ dry ton	$70/ dry ton
2010	0.37	12.49	20.52	27.42	32.32	33.95
2015	7.62	64.36	101.46	136.17	162.27	175.29
2020	38.15	119.87	176.76	237.80	277.22	301.30
2025	59.54	161.74	228.24	293.10	323.84	354.07

Agricultural Crop Residues Overview

Agricultural crop residues are lignocellulosic biomass (non-grain, non-root portion of agricultural crops) that remains in the field after harvest. The most common residues include the stalks, ears, and/or cobs from corn (stover) and straw from wheat production. Oilseed crops (soybeans, sunflower, and canola) tend to produce fewer residues than grain crops, and are generally not included for soil sustainability reasons. Residues from other miscellaneous crops (such as cotton, orchard and vineyard pruning, and grass seed production) may also be available, but usually on a very limited and diffuse basis, possibly making them infeasible. Presently, no major facilities use agricultural crop residues to produce bioethanol, but several new plants will be built in the U.S. during the next three to five years that will utilize a combination of corn stover, wheat straw, and herbaceous energy crops as feedstocks. One of these will be built by Abengoa Bioenergy somewhere in Kansas.

Because agricultural residues play an important role in controlling erosion and maintaining soil carbon, nutrients, and soil tilth, any removal for alternative purposes would require a balanced and dedicated approach to insure proper erosion control, soil tilth, and moisture retention. Removal of agricultural residues from agricultural cropland is directly influenced by a number of factors including: (1) type of erosion (wind, water), (2) soil type and its characteristics, (2) field management practices (tillage) and their timing, (3) climate, (4) physical field characteristics (% slope, soil erodibility), (5) crop and cropping rotation (single or multi-year), (6) tolerable soil loss (T), and (6) grain yield.

A national assessment was performed that examined quantities of corn stover and wheat straw required at harvest to offer adequate protection against water and wind erosion (Nelson et al., 2004). The assessment looked at seven different cropping rotations, each subject to three tillage scenarios (conventional, mulch/reduced, and no-till) on all soil types in each county of the eastern one-half of the United States. However, because of overarching assumptions made in this analysis concerning tillage scenarios and crop rotations and yields, only general inferences can be made concerning total amounts of corn stover and wheat straw potentially available removal for within a state.

Kansas Agricultural Crop Residue and Herbaceous Energy Crop Resource Assessment

The Kansas cellulosic resource base (herbaceous energy crops and agricultural crop residues) has been well researched over the past 10 years with respect to biomass potentially available for utilization as alternate energy feedstocks and select sustainability parameters such as soil erosion and water quality (Nelson et al., 2003; King, Hannifan, and Nelson, 1998). This information can provide a useful starting point for potentially advancing the state's cellulosic resource base for alternative energy production.

Corn Stover and Wheat Straw Retention and Removal

Kansas generates significant quantities of agricultural crop residues through the production of its four main commodity crops (corn, wheat, grain sorghum, and soybeans), but only a small percentage could be removed and potentially utilized for alternate energy purposes for the reasons presented above. Table 2 presents information for Kansas for a single county for continuous corn subject to general conventional (CT) and no-till (NT) field management practices and demonstrates the variation in residue retention and removal by individual soil type within this county. Supply curves (quantity of biomass at a given price) for each county could be developed from this data given assumptions regarding machinery compliments and percentage of acres subject to each tillage scenario.

The data presented in Table 2 highlight the considerable variation that exists in Allen County (as well as all other Kansas counties analyzed), both in the amount of residue that must remain on the field surface at harvest (0.202 to 8.418 dry tons for conventional tillage and 0.003 to 3.136 dry tons for no-till) and the amount that can potentially be removed given the yield of biomass at harvest.

Table 2. Variation in removable residue quantities in Allen County by soil type and tillage scenario (Nelson et al., 2003).

Soil type	**Acres**	**Residue at harvest (dry tons/acre)**	**Residue that must remain at harvest subject to CT**	**Removable residue (dry tons/ acre)**	**Residue that must remain at harvest subject to NT**	**Removable residue (dry tons/acre)**
MASON SILT LOAM	8,258	2.2	1.235	0.962	0.093	2.104
BATES LOAM	7,897	2.2	5.992	0	1.683	0.515
SUMMIT SILTY CLAY LOAM	216	2.2	4.752	0	1.1	1.097
SHIDLER-CATOOSA SILT LOAMS	295	2.2	6.869	0	2.161	0.037
CATOOSA SILT LOAM	38,544	2.2	4.366	0	0.942	1.255
DENNIS SILT LOAM	22,660	2.2	4.391	0	0.952	1.245
DENNIS-KENOMA SILT LOAMS	689	2.2	1.657	0.541	0.16	2.038
PARSONS SILT LOAM	517	2.2	3.905	0	0.768	1.429
LEANNA SILT LOAM	1,921	2.2	0.67	1.527	0.03	2.167
VERDIGRIS SILT LOAM	12,218	2.2	0.889	1.308	0.051	2.146
LANN SILT LOAM	98	2.2	0.202	1.995	0.003	2.194
ZAAR SILTY CLAY	29,705	2.2	2.806	0	0.419	1.778
CATOOSA-ROCK	12,559	2.2	8.418	0	3.136	0
ERAM SILTY CLAY LOAM	1,763	2.2	6.433	0	1.916	0.281
WOODSON SILT LOAM	37	2.2	5.191	0	1.293	0.904
DENNIS-KENOMA SILT LOAMS	438	2.2	3.418	0	0.602	1.596
KENOMA SILT LOAM	67,252	2.2	6.135	0	1.757	0.441
WOODSON SILT LOAM	25,899	2.2	3.418	0	0.602	1.596
OSAGE SILTY CLAY	3,423	2.2	0.628	1.569	0.027	2.17
ZAAR SILTY CLAY	210	2.2	0.628	1.569	0.027	2.17
OSAGE SILTY CLAY LOAM	4,222	2.2	0.889	1.308	0.051	2.146

Switchgrass Production

The energy and environmental benefits associated with herbaceous energy crop production in Kansas was analyzed by specifically modeling switchgrass yields across all soil type in each county of the eastern two-thirds of the state (King, Hannifan, and Nelson, 1998). Table 3 presents modeled data from Jefferson County that shows variation in switchgrass yields across a number of soil types over a 24-year period. In general, switchgrass production, when compared to commodity crop production on the same acreage, decreased soil erosion, surface runoff, and nitrogen transport by 99%, 55%, and 98%, respectively. For these reasons, herbaceous energy crop plantings should probably first be targeted at highly erodible or marginal lands, as they may have lower net returns and also have the most to gain in terms of environmental sustainability. Supply curves have not been developed using data similar to that shown in Table 3.

Table 3. Modeled variation in switchgrass yields in Jefferson County for select soil types.

Soil Type	Area (acres)	Maximum switchgrass yield (tons/ acre)	Minimum switchgrass yield (tons/ acre)	Average switchgrass yield (tons/acre)
PAWNEE	100,805	10.99	1.25	5.57
SHELBY	46,837	11.43	1.27	5.44
OSKA	15,058	8.98	0.17	4.07
SOGN	8,174	4.52	0.01	1.76
VINLAND	39,462	6.16	0.01	2.59
KENNEBEC	16,988	14.87	1.52	7.03
READING	6,137	12.45	1.43	6.24
GRUNDY	28,986	11.72	1.40	5.89

Potential to Produce Bioethanol from Kansas Cellulosic Resources

The actual potential to produce cellulosic ethanol from Kansas resources is multifaceted. Because large-scale production, transport, processing, and conversion of cellulosic materials have not been attempted to any real degree anywhere in the world, quite a bit is unknown with respect to essentially every area associated with the utilization of cellulosic biomass for ethanol production, including appropriate policy. The opportunities (pros) and issues (cons) listed below could directly influence cellulosic ethanol production in this state over the next 10–25 years and are based on information and data from a wide variety of agricultural, energy, environmental, and policy personnel.

Opportunities for Cellulosic Ethanol Production in Kansas

Feedstocks

Cellulosic ethanol can be produced from a diversity of resources, a fair number of them waste products such as urban wastes (wood, municipal solid waste, etc.) and agricultural crop residues. In some cases, these resources may be negative-value feedstocks and the possibility exists for utilizing them in an alternate market such as for alternative energy production which may increase their value.

Current federal legislation regarding alternative fuels production and use (previously mentioned on page 1), as well as possible expansion of this legislation, offers an opportunity for Kansas to examine its resource base and the technical and economic capabilities for large-scale alternative energy production from its cellulosic resources. Given the variety and potential magnitude of the Kansas cellulosic resource base, it is entirely possible Kansas could be a national leader in ethanol production. However, a number of sustainability issues related to energy inputs and environmental quality need to be examined in conjunction with production, harvest, and collection.

Collection Transportation Logistics and Processing and Conversion

Other plants (pilot-scale and large-scale) or will be built in North America within the next few years. Current U.S. Department of Energy funding has been awarded for six large-scale cellulosic-based ethanol plants across the United States that will, when completed and operating, provide extremely valuable information and data with respect to the entire supply chain from feedstock production, collection, transportation, and storage logistics, as well as actual chemical engineering aspects associated with ethanol production. As mentioned earlier, one of these will be built by Abengoa Bioenergy in Kansas.

Environmental Quality

Use of herbaceous energy crops such as switchgrass and big bluestem have been shown to provide select environmental quality benefits. Research conducted at Kansas State University has shown significant reductions in several water quality parameters such as sediment reduction and nutrient transfer due to herbaceous energy crop plantings for alternative energy purposes in select watersheds in northeast Kansas (Nelson, Ascough, and Langemeier, 2006). It is possible that similar results could be achieved in other parts of Kansas as well. In addition, herbaceous energy crop production on marginal acreages across Kansas (land capability classes III-VIII) could help restore/remediate these soils and also provide enhanced economic returns.

Issues with Cellulosic Ethanol Production in Kansas

Currently, there are significantly more issues than opportunities facing the industry. The major issues listed below are having or will have a direct effect on industry expansion.

Feedstocks

To meet current and forecasted U.S. gasoline consumption needs and/or replace 30% of this nation's gasoline consumption in 10 years, a significant amount of cellulosic biomass will be required (some estimates place this at six times the current biomass use). This raises several questions:

- Is it possible to use the existing agricultural land base for both food and fuel production without increasing prices?
- What are the actual cellulosic feedstocks that can be produced and utilized on a large-scale to meet these requirements and what sustainability aspects need to be considered (energy, environmental, and economic)?

- Which feedstocks can be grown/produced within close proximity to ethanol plants that are also economical in production?

Demand for feedstocks will increase as more ethanol plants come on-line; this could potentially increase overall costs due to low density feedstock and increased transportation distances, as well as needed investments in freight, rail, and/or barge systems.

Energy and Environmental Aspects

The energy-profit ratio, EPR (energy output divided by total fossil-based energy inputs) has not presently been adequately researched or defined. EPR calculations are a way to assess how renewable the cellulosic resource is. These calculations are a function of many factors such as machinery used to produce different feedstocks, nutrient and chemicals required, transportation, and conversion technologies employed. EPR values (which exist for grain-based ethanol) need to be estimated for different feedstocks and all aspects of cellulosic ethanol production.

The sustainability of cellulosic ethanol production also needs to be evaluated. Currently, crop residues are used for soil fertility and erosion prevention; no real data exist regarding the long-term environmental effect of residue removal. Also, there may be a need for additional fertilizers and chemicals. The actual environmental benefits and costs related to air, soil, and water quality have yet to be defined with respect to large-scale cellulosic production, whether from agricultural crop residues or herbaceous energy crop production. These should be monitored as the industry progresses to help provide a means of defining the “system sustainability” associated with biofuels production and removal.

Collection and Transportation Logistics and Storage

Although current methods of collecting agricultural crop residues have been shown to be costly, research is being performed with the aim of lowering in-field harvesting/collection costs. Cellulosic feedstocks are generally low-density biomass, which may render transportation prohibitively expensive, especially over large distances.

Most cellulosic biomass is harvested at relatively high moisture contents (10-15%) and, as such, can not be stored for long periods without spoilage. As the industry potentially expands and the need for greater amounts of feedstock increase, storage and associated feedstock quality as well as the ability to transport feedstock to the conversion plant will be critical and could dominate the overall cost of production.

Preprocessing and Conversion

Currently, both technology and cost of producing ethanol from cellulose are limiting factors. Acceptable technologies for cellulosic conversion to ethanol involves acid hydrolysis, but the cost is nearly four times that of a conventional grain-based, wet mill operation.

Policy

If the cellulosic ethanol industry is to grow, it will need a major commitment from the federal government, especially in the area of research and development (R&D). Recently the president promoted cellulosic biomass as a means to free this country from its “addiction to oil,” but only put $150 million toward a sustained R&D program. This amount was wholly inadequate promote the sizeable investments needed to help decrease costs in every area of cellulose utilization, from crop/feedstock production through conversion.

If, in the course of assessing large-scale cellulose production, it becomes apparent that certain energetic and environmental benefits would potentially accrue, an examination of the "monetization" of these benefits should be performed with the goal of making alternate energy from cellulose cost-effective in order to achieve the greatest societal benefit. Performance of energy-profit ratios and an examination of environmental sustainability should also be included as part of the societal benefits assessment.

Conclusions

Kansas produces a sizeable quantity of cellulose through its current agricultural production systems and could possibly utilize marginal acreage for cellulose production. However, due to the relative infancy of this industry nationwide, much is unknown about essentially all aspects of the process, from production through conversion. Kansas should immediately embark on an analysis that examines the energetic, environmental, and economic potential associated with producing alternate energy from its cellulosic resource base (ethanol, distributed generation, combined heat and power, etc.). This includes but is not limited to an assessment of the current and potential resource base with respect to land availability and competition with current commodity crops; oil prices; environmental quality concerns; transportation of finished product to high end-use markets; what barriers to expansion of all types of alternate energy derived from cellulose exist; and what technical, economic, and policy issues may affect expansion and possible remedies to these issues.

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