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TECHNICAL
REPORT

Supplying Biomass to Power Plants

A Model of the Costs of Utilizing Agricultural Biomass in Cofired Power Plants

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Summary

Concerns about greenhouse-gas emissions, volatile petroleum prices, and the national security implications of U.S. dependence on foreign energy sources have driven efforts to diversify sources of energy in the United States. Biomass energy is one potential component of a diversified energy portfolio. In addition to being a renewable resource, generally with lower life-cycle greenhouse-gas emissions than fossil fuels, the biomass resource base is large and diverse. It is also currently the only renewable resource capable of providing liquid fuels. Several pieces of national legislation have been enacted to stimulate the development of biomass energy, including the Biomass Research and Development Act of 2000,[1] the Energy Policy Act of 2005,[2] the Energy Independence and Security Act of 2007,[3] and the 2002 and 2008 farm bills.[4] A substantial amount of research on macroscopic, national-scale questions related to biomass resource availability, the environmental implications of biomass energy development, and biomass conversion technologies has been conducted over the past decade. Less research has addressed local-scale questions related to the infrastructure and logistics of supplying biomass and the costs of and constraints on the cultivation, collection, transportation, processing, and storage of biomass. Prospective biomass fuel users, such as power plants and liquid fuel refineries, need this information in order to make considered decisions on the location, size, operation, and other issues involved in making an investment in a facility that utilizes biomass.

The model developed in this work is designed to estimate the cost and availability of biomass energy resources from U.S. agricultural lands from the perspective of an individual power plant. In the example used in this report, the model estimates the availability and cost of using switchgrass or corn stover to power a cofired power plant. For the purposes of explication, we site the plant in this example in Illinois. The model provides information about the plant-gate cost of producing biomass fuel, the relative proportions of switchgrass and corn stover, the mix of different land types, and the total area contributing the supplied energy. Although the findings are sensitive to local details and quantitative results hold only for the corn-belt region, most findings are qualitatively generalizable.

[1] Title III of Pub. L. 106-224, 2000.

[2] Pub. L. 109-58, 2005.

[3] Pub. L. 110-140, 2007.

[4] Pub. L. 107-171, 2002; Pub. L. 110-246, 2008.

Modeling Approach

We model the supply of biomass to a single plant at the county level. Each unique combination of county, crop, and land type is treated as a discrete unit of supply. The model includes four crop-land-type combinations (corn stover grown on corn acreage, and switchgrass grown on cropland, cropland pasture, or Conservation Reserve Program [CRP] land). For each supply unit, we estimate the mass of biomass supplied and cost at the power-plant gate. Cost comprises land access costs, crop cultivation and harvesting costs as appropriate, and transportation and storage costs. Then the supply units are ordered by cost, from lowest to highest, to derive a marginal cost curve of supplied biomass.

We also examine the sensitivity of the results when the government levies a charge on greenhouse-gas (GHG) emissions and when the government provides a credit for carbon storage in land. The mass of biomass is estimated from the land area available and the production yield. The results are used to generate mass supply curves for the power plant. For each point on this curve, the model identifies the crops, counties, and land types supplying that biomass and the total land area used. Results are sensitive to several interdependent parameters, such as crop yields, production and handling costs, power-plant location, and tillage practices. The model encompasses the continental United States and utilizes current land rental rates, crop yields, transport costs, and input prices from available sources.

Our biomass supply model assumes that there is no competition for agricultural biomass in the area serving the plant and that producers of biomass contract individually with the power plant. Under these assumptions, we estimate the break-even price for biomass at which each biomass producer would be indifferent between supplying biomass to the power plant and alternative use of their land. If we were to consider multiple power plants, the catchment areas of those plants would overlap, increasing the average transportation distance (and, hence, costs) of supplied biomass. We capture the opportunity costs for land using rental rates, which makes biomass resource prices a function of existing alternative land uses. For corn stover, we assume that it will be produced only on land currently producing corn. By assuming that the costs of inputs are fixed parameters, we focus on the short-term decision problem faced by a single power plant to procure supplies of fuel.

Results

Utilizing the example of a power plant in Illinois, we conduct our analysis for a base-case scenario. We then examine the sensitivity of the results to changes in several parameter values. The base-case conditions for the example are summarized in Table S.1. These conditions are intended to reflect our best understanding of uncertain parameters and plausible decisions regarding the design of a biomass energy supply system.

A supply curve for the base-case scenario is shown in Figure S.1. This figure shows the biomass production cost as a function of dry weight tons.[5] For reference, we assume that 1 dry weight ton of switchgrass or corn stover equals 17 GJ. For sake of comparison, 1 ton of as-

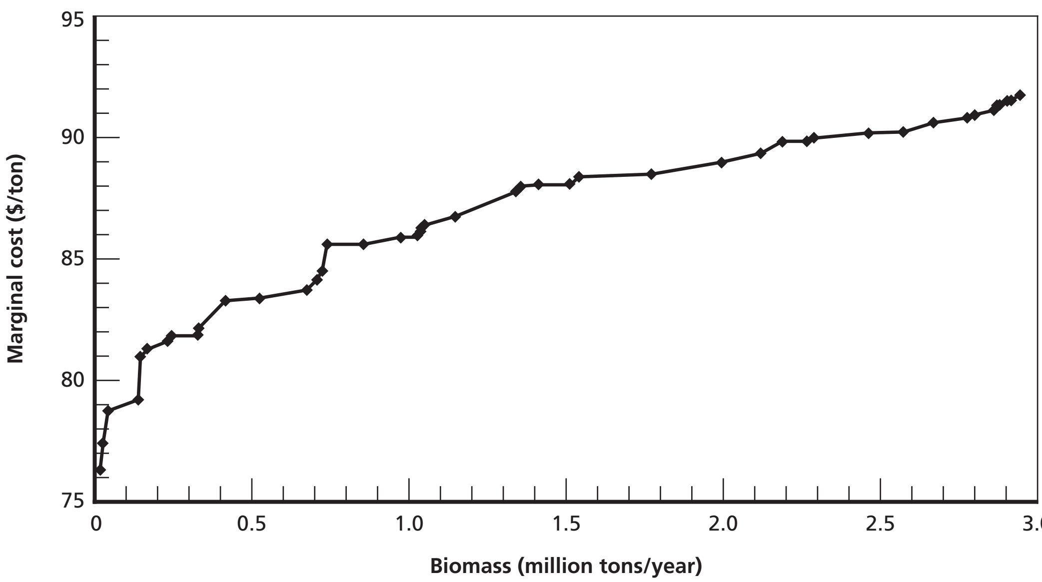
[5] It is common to normalize biomass cost and availability metrics to "dry tons of biomass" due to the variability in moisture content between different biomass types and at different points in the process of bringing biomass to market. Freshly harvested biomass can contain up to 50 percent (by weight) moisture, whereas processed and delivered biomass can contain as little as 5 percent moisture.

Table S.1
Base-Case Scenario Conditions for Illinois Example

Parameter	Value
Power-plant demand	3 million dry tons of biomass per year (approx. 50 million GJ per year)
Power-plant location	Jasper County, southern Illinois
Centralized storage	Included
Production costs	Best estimates
Carbon cost/credit	Excluded
Corn tillage practice	Current tillage mix
Crop yields	Best estimates
Land area available	100% of corn acreage, cropland pasture, and CRP land; 10% of cropland

NOTE: GJ = gigajoule.

Figure S.1
Energy Supply Curve for Base-Case Scenario



RAND *TR876-S.1*

received coal typically burnt in power plants in Illinois contains 18.8 GJ, so 1 dry weight ton of biomass has the energy equivalent of 0.9 tons of coal.[6]

We terminate the supply curve at 3 million tons (51 million GJ per year), which, when burned continuously, would produce 500–600 megawatts (MW) electrical power. As such, it represents the upper limit of the supply of biomass to a single plant. This would be enough to fuel a 30-percent biomass, 70-percent coal cofiring arrangement for the largest coal-fired

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[6] This heating value is representative of subbituminous coals from the Western United States. These coals are commonly used in Illinois due to the low sulfur content. Local coals are of the bituminous rank and have heating values up to 25 GJ per ton.

power plants in Illinois (about 1,500 MW). In practice, the amount of biomass supplied would be smaller.

The results show that the production cost ranges between $76 and $91 per dry ton ($4.50 and $5.40 per GJ), which is broadly consistent with other estimates for biomass feedstock prices. In contrast, coal consumed in power plants in Illinois sold at an average price of $1.55 per GJ in 2008–2010. The energy supply for the base-case scenario is drawn from a mix of corn stover and switchgrass from 22 counties surrounding the example power plant, a supply area with a radius of about 70 miles. To produce this amount of biomass, 1.9 million acres is needed. The mix of crops and land types for the base-case scenario for this example is shown in Figure S.2, which shows that 38 percent of the energy comes from switchgrass and 62 percent of the energy comes from corn stover. About two-thirds of the switchgrass energy comes from cropland, and about one-third comes from cropland pasture. The mix of crops and land types is modulated by transportation costs—supply from the sources with lowest land and production costs (generally, switchgrass grown on cropland pasture) is constrained by transportation costs, which increase with distance from the power plant. At higher production levels, more-expensive cropland near the power plant is used to supply biomass, trading increased transportation costs for increased land rent.

The base-case scenario represents our default estimate of the parameter values, but many parameter values are uncertain, either because they fluctuate (e.g., crop yields, input prices) or because their values depend on decisions about the design of a biomass production system (e.g., power-plant location, crop and land type, tillage practices, biomass storage). Consequently, we conducted sensitivity analyses by estimating a number of alternative supply curves, altering various parameter settings. The results of the sensitivity analyses are summarized in Table S.2.

There is substantial uncertainty concerning biomass crop yields. Furthermore, the scientific community does not have a very good sense of the potential for yield growth as seed varieties and management practices improve. Yield estimates for best-case conditions (95th-percentile switchgrass yields or collection quantities associated with no-till corn cultivation) are about 40 percent and 70 percent greater than our base-case assumptions for switchgrass and corn stover, respectively, although these higher estimates probably reflect minimum yield

Figure S.2
Distribution of Land Types for Base-Case Scenario for Illinois Example

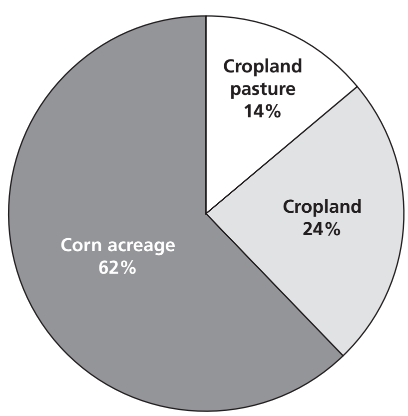

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Table S.2
Summary of Sensitivity Analyses

Scenario	Average Cost ($/ton)	Average Cost ($/GJ)	Harvested Area (million acres)	Fraction of Energy from Switchgrass
Base case	87	5.12	1.9	0.37
95th-percentile switchgrass yields	74	4.36	0.36	1.0
No-till corn cultivation	81	4.76	1.5	0.06
Increase stover production cost 50%	93	5.45	0.51	1.0
Increase switchgrass production cost 50%	90	5.29	2.7	0.00
Increase both production costs 50%	110	6.44	1.5	0.51
Power plant in central Illinois	86	5.06	2.4	0.02
Power plant in southernmost Illinois	84	4.94	0.55	0.97
No intermediate storage	70	4.10	2.0	0.34
Corn stover only	90	5.29	2.7	0.00
Switchgrass only	93	5.45	0.51	1.0
Supply from corn acreage only	90	5.29	2.7	0.0
Supply from cropland only	96	5.66	0.49	1.0
Supply from cropland pasture only	105	6.20	0.53	1.0
Supply from CRP land only	104	6.12	0.54	1.0
Carbon cost = $20/metric ton CO_2e	89	5.26	0.49	1.0
Carbon cost = $100/metric ton CO_2e	67	3.97	0.49	1.0

NOTE: CO_2e = carbon dioxide equivalent. The declining average cost of biomass as the cost of carbon increases is due to an assumed credit for carbon sequestered by the switchgrass.

increases over the long term. These yield increases would decrease total supply costs by about 17 percent and 10 percent for switchgrass and corn stover, respectively. There is also considerable uncertainty about the costs of switchgrass production and harvesting and corn-stover collection. Production costs account for about half of the total supply cost, so, if production costs for both crops are higher than expected, total costs increase proportionally by about half as much as the increase in production costs.

Factors that vary with system design include power-plant location, the use of intermediate storage, crop and land-type constraints, and carbon costs. Within central and southern Illinois, the location of the power plant has a relatively small effect (plus or minus approximately 5 percent) on energy cost. However, location has a significant effect on the distribution of the lowest-cost biomass crops, which changes from nearly pure corn stover in central Illinois to nearly pure switchgrass in southern Illinois. Biomass crops are harvested once or twice per year, so biomass fuel must be stored to provide year-round fuel to a power plant. Eliminating intermediate storage would reduce costs by about 20 percent. However, without intermediate storage, biomass would need to be stored on farms or at an energy facility, which would also entail some costs. Eliminating intermediate storage might only transfer costs elsewhere without reducing total costs.

Because corn-stover and switchgrass costs are similar, restricting production to one crop or the other (e.g., if the cost or access to one changed significantly) has a relatively small effect on total cost (less than 7 percent) because eliminating one crop shifts production to the other crop with relatively little change in total cost. Restricting switchgrass production to a particular land type could have a more-substantial effect on costs. Restricting switchgrass production to cropland pasture or CRP land can increase supply costs by as much as 21 percent, primarily because the area of these lands is limited in the region considered, requiring greater transportation distances. A government-imposed charge on emissions of carbon dioxide and credit for carbon storage can have a large effect on both total supply cost and crop and land-type distribution. As charges and credits increase, supply shifts entirely to switchgrass on cropland. This is due to the reduced life-cycle GHG emissions associated with cultivating switchgrass as compared to corn stover—namely, removal of corn stover has been shown to lead to releases of soil carbon, resulting in a net penalty to corn stover, while switchgrass has been shown to sequester carbon in its root system, resulting in a net benefit.

Implications for the Supply of Biomass

We conclude our analysis by exploring how variations in crop yields and various charges for emissions of GHGs would influence the supply of biomass to a cofired power plant. We analyze the characteristics of supplying biomass to an energy facility in four cases: the base case described above, a case in which switchgrass yields are reduced by 20 percent, a case in which corn-stover collections are reduced 20 percent, and a case in which GHG emissions are priced at $25 per ton of CO_2e.

The cost of delivering biomass does not change significantly under the four cases. The average cost of supplying 3 million dry tons ranges from $86 to $89 per dry ton. The cost does not vary much because corn stover and switchgrass have similar costs and freely substitute for one another. Changes in supply area and land use are more significant. Our analysis reveals three important implications for amount and distribution of crop and land types that supply biomass fuels for energy production.

One, relatively small variations in crop yields can lead to substantial changes in the amount, type, and spatial distribution of land that would produce the lowest-cost biomass for an energy facility. Under reduced switchgrass yields, the lowest-cost biomass energy is supplied almost entirely by corn stover, collected over a wide area of corn acreage. Under decreased corn-stover yields, the biomass supply shifts to predominantly switchgrass. Switchgrass production requires only about one-fifth of the amount of land that corn stover does, but switchgrass production displaces food production on cropland. In addition, the highest-yielding corn acreage is to the north of the chosen plant location, while the highest-yielding switchgrass lands are to the south. This means that the geographic area over which biomass is collected changes considerably as relative yields vary. The large effect of yields on the distribution of supply could make it difficult to predict from year to year what and where the most cost-effective biomass sources will be. Plant operators would have to arrange to procure biomass from a wide range of suppliers in the vicinity of their facility to hedge against potential shifts in production and changes in costs.

Two, land and crop choices would be very sensitive to policies governing GHG emissions and carbon pricing. When a price is placed on emitting GHGs and credit given for storing carbon, the lowest-cost supply rapidly shifts to entirely switchgrass, nearly all of which is planted on converted cropland. This is due to significantly lower GHG emissions of switchgrass. In devising a supply strategy for sourcing biomass energy from agricultural lands, plant operators should be cognizant that production costs are highly sensitive to exogenous factors and that supply areas might change dramatically under relatively modest changes in key parameters.[7]

Three, our results have important implications for total land area requirements for supplying biomass fuel. Replacing one-fourth of the coal used for electricity generation in Illinois (about half of the electricity in Illinois comes from coal) with biomass fuel would require collecting corn stover from almost 12 million acres of corn crops, nearly all of the corn grown in the state. Alternatively, restricting biomass production to switchgrass would reduce the land requirement to 3.2 million acres, almost half of which would be converted food cropland. In this instance, 6 percent of the state's food crop production would be displaced by biomass production for energy. In either case, the land-use implications are substantial; environmental loading, transportation needs, and workforce requirements, among other areas, would be affected significantly.

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[7] Some of these parameters include the value of the soil-carbon penalty that results from collecting corn stover and the GHG allocations among corn coproducts. Additionally, including GHG emissions due to indirect land-use change would have an effect. Qualitatively, the results do not change: The carbon penalty associated with collecting corn stover results in it being uneconomic as a the price on GHG emissions rises.