# Local Biomass Feedstocks Availability for Fueling Ethanol Production

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Concerns about rising energy costs, energy dependence on other nations, and green house gas emissions tied to global warming have raised awareness among policy makers and the public at large about the need to develop energy sources that help reduce modern economies' reliance on fossil fuels. One of a number of alternative energy sources is biomass from agricultural and forest products (Bernstein, et al.). Increasing the use of biomass not only helps diversify the sources of energy production, but may also provide opportunities for agricultural producers to become involved in value-added agriculture, and contribute to rural development.

The majority of studies concerning biomass availability estimates involve broad national, regional, or state-wide estimates of biomass availability and costs. For example, Gallagher, et al. prescribed a method for assessing the biomass costs and supply at a macro level. The authors also provided cost estimates for various locations, and documented large differences in cost estimates between geographical areas.

In this paper we assess the availability and costs of various types of biomass that may be used to fuel a portion of an ethanol plant owned by VeraSun Energy of Brookings, and operated nearby in Aurora, South Dakota.[1] The existing VeraSun facility relies on natural gas as a source of energy.[2] The renewable biomass material is intended as a supplemental fuel source, enabling the plant to reduce its reliance on fossil fuels, enhance its production efficiency, and improve its image as a producer of green energy. Also considered are economic trade-offs involved with

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[1] The ethanol production process requires the use of fuel in the distillation process, which increases the ethanol contents from approximately eight percent of the fermented product to nearly one hundred percent of the distilled product. Additional fuel is needed in drying the distillers' grain, the main co-product in ethanol production. Drying the distillers' grain enhances the shelf life of the co-product, and the dried product is easier to handle, store, and transport than wet distillers' grain.

[2] Historically high energy prices in the spring and summer of 2006 led to an increased interest in developing ethanol plants that use coal as an energy source. However, carbon dioxide (a greenhouse gas) emissions from coal-fired ethanol plants exceed those of gas-fired ethanol plants per ton of ethanol produced, raising additional environmental concerns. High $CO_2$ emissions also create an apparent image problem for the ethanol industry, which seeks to market itself as a "green" industry.

biomass removal, including potential soil productivity losses and possible changes in crop practices. In addition, we provide cost estimates involved with harvesting, storing and transporting the biomass from the field to the ethanol plant.

## Study Area

The geographic scope of the study consists of an area located within about 50 miles from the ethanol plant. However, due to the predominant north-south and east-west road directions in the study area, and also because reliable macro-level agricultural data are available only at the county level as the smallest aggregate geographical unit of administration, the study area consists of a contiguous group of virtually rectangular-shaped counties – as opposed to a geometric circle – around the plant.

The area is divided into two types of counties. Much of the discussion in the report focuses on "tier 1" counties, which are largely located within the 50-mile radius around the production facility. The second group, referred to as "tier 2" counties, are located around the tier 1 counties, but are still partly located within the 50 mile radius from the ethanol plant.

## Cropping Systems

Biomass produced in the area surrounding the ethanol plant predominately consists of agricultural cropping residue. By far the most suitable crop residue to serve as fuel for the ethanol plant is corn stover – the above-ground plant residue usually remaining on the field after corn harvest. While soybeans are an important component of the cropping rotation system in the area, the amount of after-harvest residue is relatively small and prone to rapid disintegration and deterioration, rendering it unsuitable for collection and energy extraction (Haq). Therefore, plant materials produced from soybeans are not included in our total biomass supply estimates.

While wheat is produced in relatively small amounts in the study area, wheat straw is included as a major feedstock in this study because of its relative bulk and usefulness as a biomass feedstock. Similarly, the total area planted to oats and barley is comparatively small, but the latter two small grains are important rotation crops, and are also included in the total biomass assessment of the region.

The majority of grass hay produced in the area is currently used as livestock feed. Nevertheless, the total biomass supply estimates developed in this paper include annual grass hay production estimates for the region. Due to space limitations, the potential availability of biomass produced on cropland enrolled in the Conservation Reserve Program (CRP) is not included in this paper as a possible component of the total amount of biomass produced in the region surrounding the ethanol plant, but was assessed in an extended version of this study.

### Assessing Crop Residue Supplies

The assessment of the biomass availability in a geographical area contains inherent in accuracies because of crop yield variations, harvesting techniques, weather and soil conditions, and types of tillage used. To further complicate such efforts, meaningful regional biomass supply estimates must include a consideration of competing uses for the plant residues. That is, if a region’s crop material is traditionally used for livestock feed or bedding purposes, any additional demand for plant residue due to energy usage will likely result in increased prices in the short run, and may cause cropping pattern changes over time. Hence, detailed biomass quantity and price change assessments require comprehensive modeling techniques, incorporating biomass supply and demand drivers.

To ensure sufficient and consistent biomass supplies, all agents involved with the production, collection, storage, and transportation of biomass require compensation for their share of costs incurred. In addition, a viable biomass production and distribution system must include producer incentives, encouraging them to sell their post-harvest plant residue.

## Methodology

Biomass availability for fuel usage is estimated as the total amount of plant residue remaining after harvest, minus the amount of plant material that must be left on the field for maintaining sufficient levels of organic matter in the soil and for preventing soil erosion. Average annual crop production data for tier 1 and tier 2 counties were collected, based on annual production levels over the five-year period from 2000 to 2004 (U.S. Department of Agriculture, various years). Plant residue availability estimates were developed on the basis of crop-specific ratios of residue-to-grain yields developed by Walsh, et al. In particular, each ton of corn, oat or barley grain produced is associated with an equal amount of corn stover or straw, respectively. Further, each ton of winter (spring and durum) wheat grain results in 1.7 (1.3) tons of straw. Because about one-fourth of all wheat grown in and around the Brookings County area consists of winter wheat, the co-production of each ton of wheat grain is assumed to be a weighted average of 1.4 tons of straw.

While there are no generally agreed-upon standards for maximum removal rates, a portion of the biomass material may be removed without severely reducing soil productivity. Technically, biomass removal rates of up to 60 to 70 percent are achievable, but in practice, current residue collection techniques generally result in relatively low recovery rates (Perlack, et al.).[3] Generally, 70 percent of the total amount of post-harvest biomass material is shredded, 95 percent of the shredded material is windrowed, 70 percent of the windrow is baled, 95 percent of the baled material is transported to storage, and 95 percent of the stored material is recoverable

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[3] The low biomass recovery rate is the result of a combination of factors, including collection equipment limitations, economics, and conservation requirements. Technology advances leading to the development of single-pass equipment may allow for the joint collection of grain and residues, increased collection rates to up to 75 percent, and may help reduce concerns about soil compaction associated with the use of multiple-pass equipment.

(Sokhansanj and Turhollow). Hence, 42 percent of the total amount of crop residue is available for fuel usage under current actual conditions.[4]

The amount of biomass minimally required for maintaining soil productivity depends on agronomic conditions, including soil type, crop variety and yield, weather and climatic conditions, and tillage system used (Wilhelm, et al.). As a result of varying conditions, estimates of the amount of biomass that may be removed while maintaining soil productivity also vary widely. For example, Haq has suggested biomass removal rates of between 30 and 40 percent, and Walsh, et al. proposed collecting at least 30 to 40 percent of the available residue without reducing soil productivity.

A key determinant of an area's allowable biomass removal rate is its incidence of highly erodible cropland.[5] Using the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS) definition, less than six percent of the total cropland area in the South Dakota portion of the study area is considered highly erodible, resulting in relatively small residue amounts required to remain on the cropland after harvest. In particular, NRCS requires that 30 percent of each field be covered with plant residue in the spring (Gallagher, et al.). This corresponds to leaving 1,430 pounds per acre of corn stover, and 715 pounds per acre of wheat and other small grain straw after harvest of residue. To meet these minimum requirements, we assume that at least 35 percent of the residue must remain on the field for each crop, leaving 65 percent of the after-harvest crop residue as potentially available for fuel use.

## Costs and Benefits of Plant Residue Collection

In the absence of biomass removal, plant remains are generally incorporated into the soil as organic matter through microbial decomposition – either directly using mechanical methods such

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[4] Conversations with farmers and custom harvesters in the region anecdotally confirm such estimates.

[5] Land is considered highly erodible if it has a potential to erode at more than eight times the rate at which the soil can maintain continued productivity. At least one-third of a field must be considered highly erodible, or the highly erodible area must be at least 50 acres (U.S. Department of Agriculture, 2006).

as plowing or discing, or indirectly after having been used as animal feed or fodder. Leaving plant residue on fields after harvest provides several benefits. One is that the residue helps retain or enhance soil quality – not only because the materials contain nutrients that are recycled in the soil, but also because the organic crop materials help preserve or enhance the soil structure. Further, post-harvest crop residues help reduce the negative environmental impacts associated with the intensive use of row crops, including soil erosion and nutrient runoff. The presence of crop residue in the soil also helps sequester greenhouse gases by maintaining soil carbon levels. Further, leaving plant residue on fields – as opposed to collecting the material for use elsewhere – helps avoid soil productivity losses due to soil compaction caused by heavy machinery used for crop residue collection and transportation (Wilhelm, et al.).

Cost estimates of applying fertilizer to the soil to replace nutrients lost due to biomass removal depend in part on fertilizer prices. In 1997, the cost of replacing nutrients lost due to residue removal with fertilizers was $6.47, $4.99, $7.49, and $7.86 per ton of corn stover, wheat straw, barley straw, and oat straw, respectively (Gallagher, et al.). Using 2006 fertilizer prices of $360, $325, and $260 per ton of nitrogen, phosphorus and potassium, respectively, the fertilizer value would have increased to $9.37, $7.55, $11.59, and $12.25 per ton of corn stover, wheat straw, barley straw, and oat straw removed, respectively, based on the weighted fertilizer content contained in the biomass.

Post-harvest plant residue removal normally requires at least three additional field operations, including collecting the material into rows, compacting it into bales, and transporting the bales within and from the field. Each procedure potentially increases soil compaction and decreases cropland productivity.[6]

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[6] Options exist to reduce soil compaction, such as waiting until the soil freezes to support heavy equipment, using relatively small or light equipment, or hauling small loads. Alternatively, increasing the number of tires or using wide tires to reduce their compactive pressure also helps reduce soil compaction rates, but increases the area compacted (Wilhelm, et al.). An additional way to reduce soil compaction is to use single-pass harvesting

While present harvesting techniques may be adequate for meeting the current biomass demand and conservation requirements, plant residue collection efficiency and cost effectiveness may increase as biomass markets develop in the future. For corn stover, current harvesting techniques may include the use of flail mowers, which are used to reduce stalk size and leave the plant material in windrows for baling. Alternatively, rakes may be used for windrowing, but raking decreases product quality by mixing dirt with plant residue, thus causing additional baling equipment wear. After drying in the field, the stover is baled into large round (or square) bales, each weighing between 800 and 1500 (600 and 900) pounds. Wheat and other small grain straw is generally left in a windrow after harvest for later baling. Similar to corn stover, the straw may be baled into large round or large square bales. Unless the remaining grain stubble is light, the remaining plant material leaves sufficient cover for conservation requirements. Large round balers are less expensive than large square ones, but square bale storage and transporting efficiencies exceed those of round bales.

## Cropping Residues Availability and Costs of Collection and Transportation

The recoverable amount of biomass available in the study area is listed in Tables 1 and 2. Based on an average recovery rate of 3,150 pounds (or 1.58 tons) of corn stover per acre, the total amount of corn stover available in tier 1 counties is 1.16 million tons. In comparison, relatively small amounts of wheat (93.2 thousand tons) and oat straw (11.2 thousand tons) are recoverable. All recoverable amounts would meet the minimum residue requirements for NRCS. Although generally used for livestock feed, other hay production is included to show the production potential of Conservation Reserve Program acres that may become available. Further, Table 2 shows that 1.8 million tons of corn stover and 271.8 thousand tons of wheat straw could be

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equipment, which would collect the grain and the residue in one pass. While single-pass equipment would result in smaller compaction rates than using multiple pass machinery, the equipment needed would likely be heavier and thus cause greater compaction than current grain harvesters (Atchison and Hettenhaus; and Perlack, et al.)

recovered per year, using average production levels for tier 2 counties of South Dakota and Minnesota.

Tables 3 through 5 illustrate the costs of collecting and transporting the stover, straw, and hay to the plant. Mowing charges are based on the custom rates reported for eastern South Dakota in 2004 (U.S. Department of Agriculture, 2004). To account for cost inflation over time, an additional 15 percent was added to the 2004 rate of $6.68 for a total of $7.75. Other recovery costs include $6.50 per large square bale for baling, and $1.00 per bale for moving the bales to the edge of the field. The estimates are based on the assumption that the biomass is delivered directly to the plant and stored at the edge of fields. Transportation costs would increase if remote and centrally located storage areas would be required for collecting residues because of additional product handling.

In Table 3, the costs associated with collection and transporting corn stover to the processing plant is $48.22 per ton. These costs include $15.72 in returns to producers (covering fertilizer replacement costs of $9.37 per ton and a $6.35 per ton producer incentive to sell the stover), $6.15 per ton for transportation and handling, and $26.35 per ton for flail mowing, baling, and moving the baled stover to the edge of the field.

The biomass cost estimates provided above may be overly optimistic. The successful development of a biomass market may require the use of additional payments to producers, whether in the form of farmer incentives, loading costs, or moving bales to the edge of the field. Also, actual transportation costs depend on time, distance traveled, and equipment used.

## New Business Development

The corn harvest is a very time-pressed operation for agricultural operators whose primary concern is harvesting the corn grain crop. Because the window of opportunity involved in the corn harvest is limited, many producers may not have time to collect and bale the residues. As an alternative, crop residue collection and transportation may result in new businesses development, including enterprising non-agricultural producers seeking to develop their own business, or small producers who custom harvest to supplement their farm income. Transporting the plant residue to the plant or a central storage area may be conducted by agricultural producers or local trucking companies.

## Concluding Comments

This paper provides an assessment of crop residue biomass quantities potentially recoverable within a distance of approximately 50 miles from Aurora, SD. The biomass would serve as an alternative fuel source in the ethanol production process. The potentially available biomass varies by crop variety and crop yield, but is also dependent on the minimal amount of residue needed to avoid soil erosion, and the technical capability of harvesting equipment to collect the residues. The primary source of crop residue currently available for collection in the region is corn stover, but straw produced as a co-product in small grain production is also considered in assessing the availability of the total amount of biomass in the study area.

Currently available harvesting equipment allows producers to collect around 45 percent of the available corn stover on a 130 to 150 bushel per acre field. Residue collection rates exceeding such levels would result in a failure to meet NRCS requirements for soil conservation. In addition to technical factors, the amount of biomass available for fuel usage depends on agricultural producers' willingness to sell their crop residues. In turn, farmers' readiness to sell biomass depends on post-harvest weather conditions, time constraints, equipment availability during the corn grain harvest, and the relative fertilizer value of plant residue remaining on the field. Further, farm-level biomass prices must be sufficiently high to compensate participating farmers for any labor and capital usage associated with collecting and transporting the biomass. In addition, farmers would need to receive financial incentives for removing the plant residues.

Results of the study indicate farm-level costs of approximately $42.07 per ton of corn stover. Transportation costs to the plant depend on whether the bales would be transported directly to the plant or to a central storage area, but in this study the estimated total costs involved with collecting, handling and transporting the stover is $48.22 per ton.

The current study does not fully attribute all costs involved with collecting, transporting, and storing the biomass directly to the biomass enterprise. Instead, we assume that the biomass market would utilize existing infrastructures and currently available equipment without explicitly attributing the additional costs to the newly formed biomass enterprise. A related caveat is that the study the risks does not account for risk sharing amount various agents of a newly formed biomass sector, including biomass producers, distributors, and purchasers. The successful development of a biomass market may involve the use of risk-sharing instruments such as production or marketing contracts, in order to help alleviate some of the risks borne by among agricultural producers, marketing agents, and the ethanol producer. Hence, the cost estimates presented in this study provide a lower bound of the actual costs involved with collecting, handling, and transporting the biomass to the plant's central location in the area.

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Table 1. Average annual recoverable corn stover, wheat, oat and barley straw and other hay production, Tier 1 counties, South Dakota and Minnesota, 2000-2004

| County | Recoverable Corn Stover (1,000 tons/yr) | Recoverable Wheat Straw (1,000 tons/yr) | Recoverable Oat Straw (1,000 tons/yr) | Recoverable Barley Straw (1,000 tons/yr) | Other Hay Production (1,000 tons/yr) |
|---|---|---|---|---|---|
| South Dakota | | | | | |
| Brookings | 175.6 | 14.4 | 2.1 | - | 32.6 |
| Deuel | 93.8 | 17.2 | 2.6 | - | 20.4 |
| Hamlin | 122.7 | 14.4 | 1.6 | - | 14.7 |
| Lake | 157.6 | 3.2 | 1.0 | - | 10.9 |
| Moody | 166.9 | 3.3 | 0.5 | - | 12.0 |
| Kingsbury | 164.0 | 29.0 | 1.2 | - | 21.7 |
| SD Total | 880.6 | 81.4 | 9.1 | - | 112.3 |
| | | | | | |
| Minnesota | | | | | |
| Lincoln | 136.6 | 11.8 | 1.1 | - | 5.7 |
| Pipestone | 147.6 | - | 1.0 | 0.7 | 6.3 |
| MN Total | 284.2 | 11.8 | 2.1 | 0.7 | 12.1 |
| | | | | | |
| SD+MN total | 1,164.7 | 93.2 | 11.2 | 0.7 | 124.4 |

Note: Recoverable corn stover is 3,150 pounds per acre.

Table 2. Average annual recoverable corn stover, wheat, oat and barley straw, and other hay production, tier 2 counties, South Dakota and Minnesota, 2000-2004

| County | Recoverable Corn Stover (1,000 tons/year) | Recoverable Wheat Straw (1,000 tons/year) | Recoverable Oat Straw (1,000 tons/year) | Recoverable Barley Straw (1,000 tons/year) | Other Hay Production (1,000 tons/year) |
|---|---|---|---|---|---|
| South Dakota | | | | | |
| Clark | 12.8 | 37.9 | 1.6 | 0.3 | 29.8 |
| Codington | 92.1 | 37.5 | 3.1 | 0.4 | 17.9 |
| Grant | 98.7 | 154.2 | 1.1 | 0.5 | 14.1 |
| Miner | 93.2 | 8.7 | 1.1 | - | 16.1 |
| Minnehaha | 231.8 | 0.7 | 1.8 | - | 18.8 |
| SD Total | 637.6 | 239.0 | 8.7 | 1.2 | 96.6 |
| | | | | | |
| Minnesota | | | | | |
| Lac Qui Parle | 241.9 | 13.8 | | - | 7.9 |
| Lyon | 269.4 | 4.1 | 1.1 | - | 2.6 |
| Murray | 266.8 | 1.0 | 2.2 | - | 5.1 |
| Rock | 191.9 | - | 1.2 | - | 8.1 |
| Yellow Medicine | 275.9 | 13.8 | 0.6 | - | 4.6 |
| MN Total | 1.245.9 | 32.8 | 5.0 | - | 28.4 |
| | | | | | |
| SD+MN total | 1,883.4 | 271.8 | 13.7 | 1.2 | 125.0 |

Table 3. Corn stover collection and transportation cost estimates

| Assumptions | | | | | |
|---|---|---|---|---|---|
| Tons per acre | 1.58 | lbs per bale: 700 | | Tons per load: 25.2 | |
| Sq bales per acre | 4.5 | Bales per Load 72 | | | |
| Operations | | | Per Bale | Per Ton | Per Acre |
| Flail Mowing per acre | 7.75 | | 1.72 | 4.92 | 7.75 |
| Baling per Bale (Lg Sq) | 6.50 | | 6.50 | 18.57 | 29.25 |
| Transport to Field Edge | 1.00 | | 1.00 | 2.86 | 4.50 |
| Return to Producer | | | | | |
| Fertilizer Replacement | 14.76 | | 3.28 | 9.37 | 14.76 |
| Incentive to Producer | 10.00 | | 2.22 | 6.35 | 10.00 |
| Transport to plant | | | | | |
| Loading | 40.00 | | 0.56 | 1.59 | 2.50 |
| Transport to plant | 75.00 | $3.50×20 mi | 1.04 | 2.98 | 4.69 |
| Unload | 40.00 | | 0.56 | 1.59 | 2.50 |
| Total Transportation | | | 2.15 | 6.15 | 9.69 |
| Total Collection and Transportation Costs | | | 16.88 | 48.22 | 75.95 |

Table 4. Wheat straw collection and transportation cost estimates

| Assumptions | | | | | |
|---|---|---|---|---|---|
| Tons per acre | 1.00 | Pounds per bale 600 | | Tons per load 21.6 | |
| Sq bales per acre | 3.3 | Bales per Load 72 | | | |
| Operations | | | Per Bale | Per Ton | Per Acre |
| Flail Mowing per acre | 0.00 | | 0.00 | 0.00 | 0.00 |
| Baling per Bale (Lg Sq) | 6.50 | | 6.50 | 21.67 | 21.67 |
| Transport to Field Edge | 1.00 | | 1.00 | 3.33 | 3.33 |
| Return to Producer | | | | | |
| Fertilizer Replacement | 10.56 | | 3.17 | 10.56 | 10.56 |
| Incentive to Producer | 10.00 | | 3.00 | 10.00 | 10.00 |
| Transport to plant | | | | | |
| Loading | 40.00 | | 0.56 | 1.85 | 1.85 |
| Transport to plant | 75.00 | $3.50×20 mi | 1.04 | 3.47 | 3.47 |
| Unload | 40.00 | | 0.56 | 1.85 | 1.85 |
| Total Transportation | | | 2.15 | 7.18 | 4.18 |
| Total Collection and Transportation Costs | | | 15.83 | 52.71 | 52.71 |

Table 5. Grass hay and CRP hay collection and transportation cost estimates

| Assumptions | | | | | |
|---|---|---|---|---|---|
| Tons per acre | 1.78 | Pounds per bale 700 | | Tons per load 25.2 | |
| Sq bales per acre | 4.5 | Bales per Load 72 | | | |
| Operations | | | Per Bale | Per Ton | Per Acre |
| Swathing | 9.75 | | 2.17 | 5.48 | 9.75 |
| Baling per Bale (Lg Sq) | 6.50 | | 6.50 | 18.57 | 29.25 |
| Transport to Field Edge | 1.00 | | 1.00 | 2.86 | 4.50 |
| | | | | | |
| Return to Producer | | | | | |
| Per Acre | 30.00 | | 6.67 | 16.85 | 30.00 |
| | | | | | |
| Haul to plant | | | | | |
| Loading | 40.00 | | 0.56 | 1.59 | 2.50 |
| Transport to plant | 75.00 | $3.50×20 mi | 1.04 | 2.98 | 4.69 |
| Unload | 40.00 | | 0.56 | 1.59 | 2.50 |
| Total Transportation | | | 2.15 | 6.15 | 9.69 |
| Total Collection and Transportation Costs | | | 18.49 | 49.91 | 83.19 |