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Bio Tech Brief

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WRBEP study finds plentiful corn residue resources around Nebraska community

The area around Kearney, NE, could produce at least 240,000 bone-dry tons (BDT) of corn residue per year for use as feedstock for ethanol production, according to a recent study. That's enough to produce at least 12 million gallons of ethanol per year.

The University of Nebraska-Lincoln's Industrial Agricultural Products Center completed the study of potential residue collection for the Western Regional Biomass Energy Program (WRBEP).

An earlier study completed by the National Renewable Energy Laboratory (NREL) for WRBEP characterized a 70-mile radius around Kearney as an area with enough corn residue to supply a cellulosic fermentation facility. However, it did not examine the feasibility of collecting and processing the residue.

The WRBEP study also evaluated a slightly different area to reflect community associations and growing patterns. It extends farther east than the area evaluated by NREL.

The area evaluated comprises 25 counties, with 55 percent cultivated. Corn is grown on 3.21 million acres, making it the major crop.

Based on 1990 figures, the area contained 16,400 farms with more than $1,000 each in annual sales of agricultural products, with 89 percent owned by individuals.

The WRBEP study sought to identify the amount of residue that reasonably could be recovered. It examined:

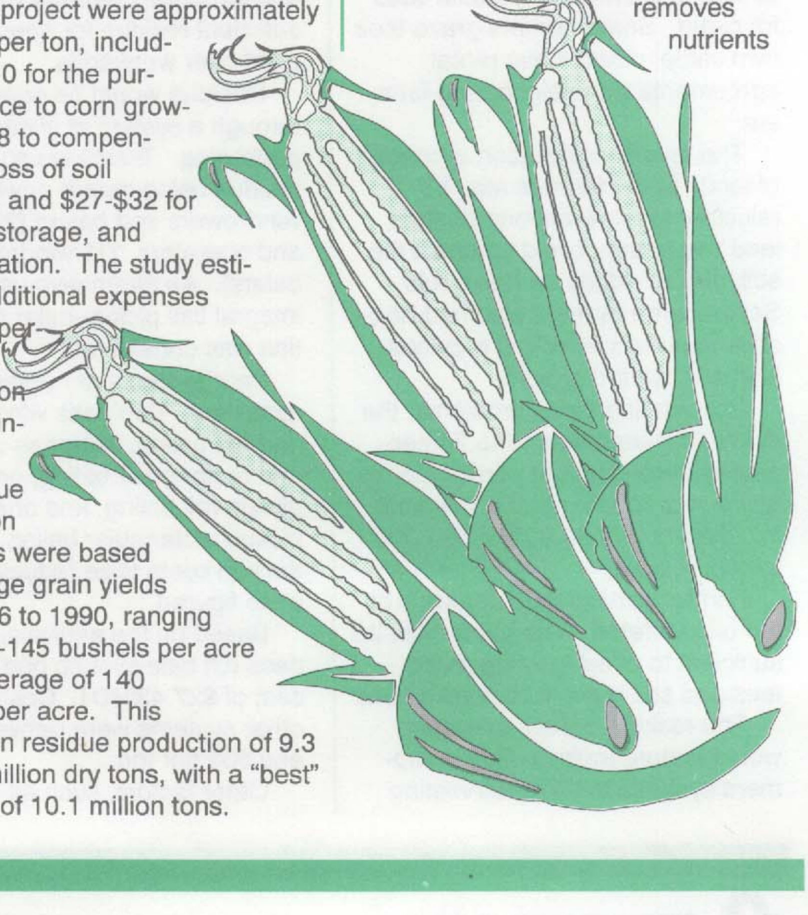
- Site characterization
- Competing uses of corn residue
- Price required by farmers
- Residue collection
- Field operations
- Methods of harvesting
- Transportation and storage

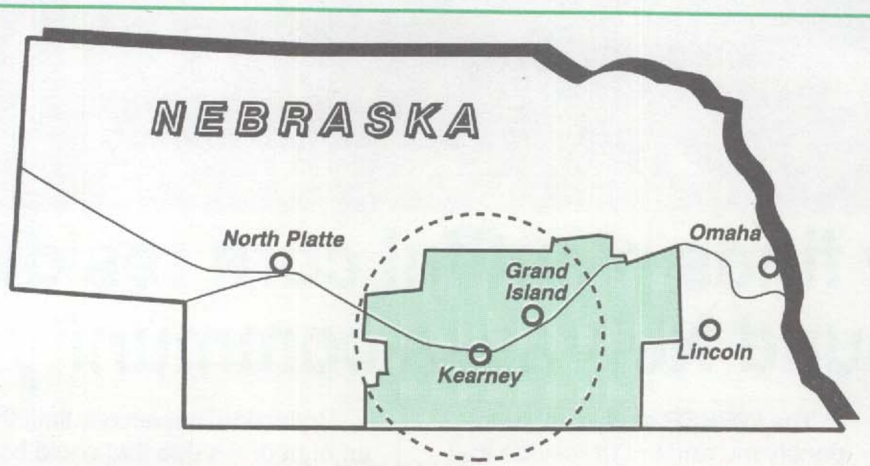
Estimated costs of a corn residue recovery project were approximately $41-$50 per ton, including $7-$10 for the purchase price to corn growers, $7-$8 to compensate for loss of soil nutrients, and $27-$32 for harvest, storage, and transportation. The study estimated additional expenses of 10-20 percent for supervision and administration.

Residue production estimates were based on average grain yields from 1986 to 1990, ranging from 135-145 bushels per acre for an average of 140 bushels per acre. This resulted in residue production of 9.3 to 12.8 million dry tons, with a "best" estimate of 10.1 million tons.

Collection procedures limit the amount of residue that could be used as feedstock. Equipment currently available could only collect 40 percent of residue from fields. There also are competing uses for residue, including soil conservation and cattle grazing.

Soil conservation requirements make annual harvesting of residue impractical. Residue removal also removes nutrients





▪▪▪ **Original Site – NREL study**

Characterization Area – WRBEP study

from the soil, and Federal regulations require farmers to comply with soil conservation programs to be eligible for farm subsides, crop insurance, and disaster assistance.

Corn residue also is an attractive source of fall and early winter feed for cattle. Some farmers graze their own cattle; others have rental agreements with neighboring farmers.

The final consideration is control of land. Many farmers may be reluctant to allow anyone on their land where they could compact the soil, disturb ridges, or leave ruts. Several area farmers also had negative experiences with a previous biomass-related project.

Considering these problems, the study estimated that 15 to 30 percent of farmers might participate on a two-year rotating basis, resulting in collection of 290,000 to 580,000 tons of residue.

Farmer participation depends on the price offered. The price must be sufficient to offset grazing rental fees and soil nutrient replenishment.

The residue collection system would feature multiple field equipment systems to allow harvesting completion during a 60-day window of opportunity. Fifty dispersed storage sites would be used to reduce losses in case of fire. Bales would be transported from storage to the production plant five days a week, and temporary storage would hold sufficient residue for operating the plant over weekends.

Residue would be collected through a system of windrowing and packaging. Teams would collect residue using tractor powered windrowers and balers (222 tractors and operators, 111 windrowers, 111 balers). An alternative using an integral flail pickup-baler combination was considered.

Four systems of harvesting were assessed: Two pass windrowing and roll baling, two-pass windrowing and rectangular baling, one-pass pickup roll baling, and one-pass pickup rectangular baling. Preproduction costs (size reduction) also were figured.

Based on the analysis, the two-pass roll bale system had the lower cost of $27.43/BDT. Costs of the other systems were between $32 and $33 per ton.

Other factors, such as support equipment required, could affect the economic analysis of each system, and the study noted these factors should be evaluated before a final decision.

Storage considerations include degradation of feedstock during storage. If residue degrades significantly, extra residue must be collected to compensate, and this would significantly impact the economic feasibility of the project.

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Announcements

WRBEP News

Study examines feasibility of corn residue collection around Kearney

The area around Kearney, NE, could provide at least 240,000 bone-dry tons (BDT) of corn residue per year for use as feedstock for ethanol production, according to a recent study. That's enough to produce at least 12 million gallons per year.

The University of Nebraska-Lincoln's Industrial Agricultural Products Center completed the study of potential residue collection for the Western Regional Biomass Energy Program (WRBEP). The resulting report examined feedstock, collection methods, competing uses of corn residue, transportation and storage, and other factors affecting project feasibility.

A WRBEP study completed in 1990 characterized a 70-mile radius around Kearney as an area with enough biomass to supply a cellulosic fermentation facility; that study, however, primarily focused on volume, not operational feasibility. The University of Nebraska study sought to identify the amount of residue that could actually be collected, and associated costs.

To more accurately reflect growing patterns and community associations, the recent study identified a slightly different area comprising 10.63 million acres in 25 counties. Of this area, 5.86 million acres (55 percent) are cultivated. The area is bordered on the south and west by semiarid wheat-producing land, and on the north by sandhills where ranching is the primary activity.

Using 1990 figures, the area contained 16,400 farms that generated more than $1,000 each in annual sales of agricultural products. Individually-owned farms account for 89 percent of that total; 5 percent are corporately-owned, and partnerships and trusts account for 2 percent each. The study concluded that about 2,000 contracts with individual farms would be required to obtain 240,000 tons of residue.

The study also noted that residue available would vary from year to year, based on grain yields and weather conditions. The study assumed a yield of 140 bushels of corn per acre, the average for the five-year period from 1986-1990.

Several competing uses exist for corn residue. These include:

- Soil conservation: Residue prevents wind and water erosion, and provides nitrogen, phosphorus, and potassium nutrients for the soil.
- Grazing: Corn residue provides fall and early winter feed for cattle. Some corn farmers also raise cattle; others have rental agreements with neighbors.
- Farmers' reluctance to allow anyone on their land: Described in the report as an "indirect but very real" problem, this factor reflects a lack of willingness of some farms to relinquish control of their land. The price farmers receive for their residue must be sufficient to offset any inconvenience and alternative uses, and to cover the cost of lost soil nutrients.

Other costs include: (1) Field operations; the cost of residue collection, transportation, and storage, (2) Collection capability: a collection system must be based on timing of harvest and field equipment alternatives.

The complete system for residue collection and handling was assumed to include:

- Multiple field equipment systems to assure completion of baling within a 60-day period
- 50 dispersed area storage sites to minimize risk of fire loss
- Transportation of bales from storage sites to the plant site, 5 days per week year-round
- Temporary storage at the ethanol plant, accommodating a small inventory for weekend use when trucking would stop

The study evaluated four systems of collecting residue and concluded that a two-pass roll-bale system (a pass with a windrower to assemble the corn residue, and a second pass with a baler to collect and package it) had the lower cost at $27.43 per delivered ton, with a yield of 1 ton per acre. This system would require 222 tractors, 111 windrowers, and 111 balers.

Estimated total costs of a corn residue project were about $41-$50 per ton, including $7-$10 for purchase price and $7-$8 for nutrient compensation. The total does not include supervisory and service personnel, their vehicles and equipment.

For more information, call Kenneth Von Bargen at (402) 472-1634.

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WRBEP plans National Bioenergy Conference

The Western Regional Biomass Energy Program (WRBEP) will sponsor a National Bioenergy Conference and Regional Biomass Energy Program State Coordinators Meeting in Reno, NV, Oct. 2-6, 1994.

Cosponsored by the State of Nevada Conservation Commission, the conference will facilitate the exchange of hands-on practical information on biomass energy technologies, feasibility studies, demonstrations, pilot projects, and related issues. Other intrested cosponsors should contact WRBEP.

The conference is designed for members of the biomass energy industry, the applied research community, and agencies involved in biomass energy developments. It is the sixth in a series of conferences organized by Regional Biomass Energy Programs.

For more information call David Swanson or Steve Sargent, WRBEP program representatives, at (303) 275-1704.

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Feasibility of Corn Residue Collection in Kearney, Nebraska Area

Report of Findings
April 1993

for
Western Regional Biomass Energy Program

by
University of Nebraska-Lincoln
Industrial Agricultural Products Center

Principal Investigators: Renee Sayler and Kenneth Von Bargen
Co-Investigators: Michael Meagher, William Scheller, Michael Turner

Table of Contents

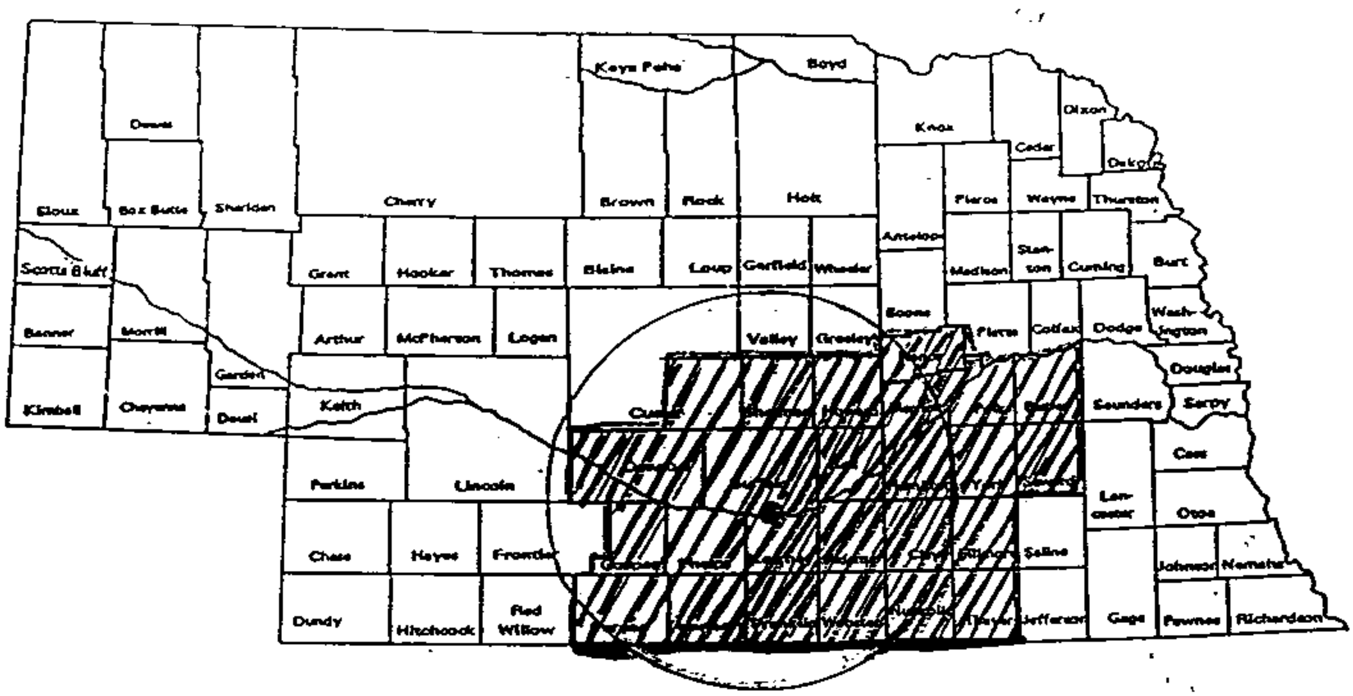
The goal of this project was to examine the opportunities for and challenges to corn residue collection and its subsequent use as a fermentation feedstock. In 1990, Hinman, et al. identified a circular site (70-mile radius) around Kearney, Nebraska as an area producing sufficient biomass to supply a cellulosic fermentation facility. His study was national in scope and looked primarily at issues of volume and not operational feasibility. Our objective was to look closely at the 25 counties illustrated in Figure 1, and to identify the collectable quantity of corn residue and the cost associated with supplying a fermentation facility. The minimal volume of residue required by the facility was defined by the Western Region Biomass Energy Program (WRBEP) as 240,000 dry English tons of residue per year.

This task was accomplished by characterizing the Kearney site with respect to crops produced, annual yield of corn, variation in annual yield, percent of land in production, number of farms, farm ownership, tillage practices and current residue uses. In addition, issues of mechanical collection, packaging, transportation, storage and costs were addressed.

The scope of this study allowed for evaluation of residue collection for only one crop. Because of differences in residue production, collection, growing seasons and tillage practices for different crops, the findings for one crop are not readily transferable to other crops. Our efforts focused on corn because it constitutes the majority of the crop land under cultivation in the Kearney area.

Figure 1

Nebraska Characterization Site



— Original Site

Characterization Area

Kearney, Nebraska

SITE CHARACTERIZATION

The Kearney study site is bordered on the south and west by semi-arid land where wheat is more commonly grown, and on the north by sandhills that support ranching. The Platte River and the Interstate 80 highway run east and west through the center of the area and three principal north-south state highways (183, 281, and 81) run through the area.

Current Land Use

The area evaluated consists of 10.63 million acres of land. Fifty-five percent of the land, 5.86 million acres, is cultivated. Corn is grown on 3.21 million acres of the cultivated land. Figure 2 illustrates the types and amounts of crops grown in the Kearney area.

In 1990, there were approximately 16,400 farms in the 25-county area which generated $1,000 or more in annual sales of agricultural products. Eighty-nine percent (89%) of the farms are owned by individuals, five percent (5%) are owned by corporations, two percent (2%) by partnerships and two percent (2%) by trusts.

Average farm size for the state in 1990 was 841 acres. This average includes large ranches in the sandhills. Consequently, the average size of farms in the Kearney area is somewhat smaller. The trend since 1983 has been for the number of farms to decrease by 1.2 percent per year, and for the number of acres per farm to increase by 2.2 percent per year. Although there are bigger farms and fewer farmers, there are potentially over 16,000 individual contracts to negotiate if 100 percent of the farmers participate in supplying a fermentation facility. More realistically, a plant would need to negotiate approximately 2,000 contracts to obtain the required 240,000 tons of residue. This large number of suppliers results in little negotiating power for any one farmer but can be an administrative nightmare if not handled appropriately by the fermentation facility.

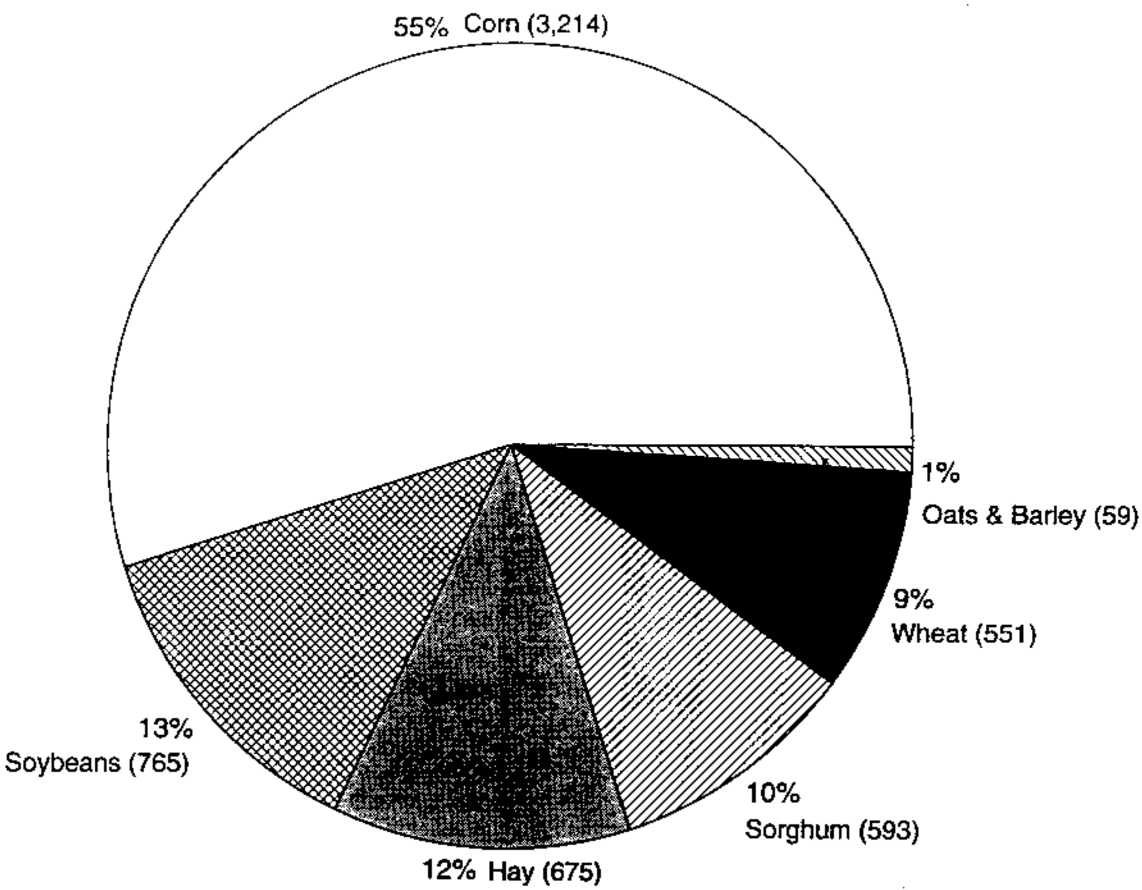


Figure 2. Crops grown in 25-county Kearney area (000s acres).

Corn Residue Produced

There are no statistics kept on the amount of corn residue produced. Thus, residue production must be estimated. Research clearly indicates that residue production is related to grain production. However, the precise relationship is debatable. Estimates of grain to residue ratios for field corn range from a low 1:1 ratio to as high as a 1.38:1 ratio. Controversy over the ratio arises from the fact that in a poor growing year, ears may not fill with grain, thus the volume of residue is high in proportion to the grain produced. In this case the grain to residue ratio may be 1:1. Conversely, when the growing year is good, the ears are full and the bushels of corn per acre are high, the amount of residue is increased only slightly and the ratio may shift to as much as a 1.38:1 grain to residue ratio.

For purposes of determining residue production in the Kearney area, we have calculated high, low and best estimates for residue production. The average yields of grain per county for 1986 through 1990 were used as the foundation for calculating residue production. Residue production using a 1:1 ratio was used to calculate a "high" residue production estimate, and the 1.38:1 ratio was used to calculate a "low" estimate of residue production. A 1.27:1 ratio was used to calculate a "best" estimate for production of residue. The "best" estimate was based on our interpretation of the literature, *i.e.*, J.L. Butler's evaluation of the literature and our knowledge of the corn production practices of the area. Appendix I is a copy of J.L. Butler's evaluation of residue production literature.

The average yield of grain per acre from 1986 through 1990 for the 25-county Kearney area was 140 bushels. Average yield varied from a low of 135 bushels per acre in 1986 to a high of 145 bushels per acre in 1987. Not only did average yield vary from year to year, but there was significant variability by county each year. The range of average yield by county for this period varied from a low of 105 bushels per acre for irrigated corn in Furnas county in 1988 to a high of 166 bushels per acre in Phelps county in 1990. Appendix II documents corn yields by county for 1986 through 1990.

Using the average corn production per acre for each county from 1986 to 1990, the average annual corn residue production (low, high and best) for the 25-county area was estimated to be between 9.3 million dry tons and 12.8 million tons, with a "best" estimate of 10.1 million tons of residue. This translates to an average of 3.1 tons per acre. Appendix III documents the calculations of residue production by county.

The most efficient residue collection equipment currently available is capable of only 49 percent collection of residue. This reduces the collectable residue to about 5.0 million tons per year or a maximum of 1.50 tons per acre in the Kearney collection area. Appendix

IV documents the amount of residue that can be collected using 49% harvestability. With an estimated 51 percent loss of residue due to mechanical collection capabilities, the total amount of residue available per year is approximately 5.0 million tons (1.5 tons per acre).

COMPETING USES OF CORN RESIDUE

There are three major competitors for corn residue: soil conservation, cattle grazing and land control. Of greatest concern to many farmers is soil conservation. The concern is two-fold. Farmers are stewards of the land who understand that their future and the futures of their children depend on taking good care of the land. Many farmers in this area have witnessed the loss of land quality and the years required for rejuvenation when corn silage was removed for consecutive years. When residue is removed, organic material and nutrients are removed. According to Bill Larson, a Minnesota USDA scientist, the corn residue on one acre contains 93 pounds of nitrogen, 15 pounds of phosphorus and 112 pounds of potassium. If half of these nutrients are removed on a two or three year rotation, the nitrogen and phosphorus would need to be replaced. Potassium is abundant in Nebraska soils and would probably only need to be replaced if residue was removed every year.

Although farmers occasionally take a short term gain at the expense of their land, they are not likely to harvest residue on an annual basis. They are more likely to collect residue one out of two or three years. For these farmers, the issue is not only a financial one, but also an emotional one. Strategies to encourage participation in biomass collection will need to take this factor into consideration.

The second soil conservation issue is purely financial. Federal regulations instituted in 1985 stipulate that farmers who fail to adopt and comply with soil conservation programs jeopardize participation in federal farm subsidy, crop insurance and disaster assistance programs and/or are fined for failure to comply with soil conservation programs. One field out of compliance will exclude farmer participation in these programs. The rules for compliance are based on the amount of residue covering the field after spring planting. Residue left at the time of harvest must provide sufficient cover on the land until plant emergence the following spring. The farmer must estimate the amount of residue that will remain following winter snow, spring rains, March winds, as well as any fall and spring tillage operations. Corn stalks are tenacious in terms of overwintering,degradation and their removal would significantly affect spring ground cover.

The amount of ground cover required depends on the susceptibility of land to wind and water erosion. Flat lands with little organic content or wind breaks are susceptible to wind erosion. Land with six percent or greater slope is prone to water erosion and is required to maintain significant ground cover. In theory, it might be possible to collect residue from compliance acres, because compliance plans are based on an average amount of coverage over a three year period. However, the farmer's penalty for non-compliance requires that compensation for biomass removal be sufficient to justify taking the risk, which probably prices the biomass out of reach for fermentation purposes.

The Conservation Tillage Information Council and Soil Conservation Service indicates that 720,000 corn acres (22.7%) in the Kearney area are classified as highly erodible and thus are required to have compliance plans. Excluding these acres from collection of residue reduces by 1.1 million tons the amount of residue available. Collectible residue available in the Kearney area is thus 3.87 million tons as documented in Appendix IV.

The second competing use of corn residue is grazing. Corn residue provides an attractive source of fall and early winter feed for cattle. Many corn growers also have cow-calf operations. Other corn growers have long standing field rental agreements with neighbors for grazing of their stalks, particularly in the northwestern counties of the Kearney area which border the sandhills.

The price for grazing depends on weather, the amount of corn left in the field and the amount of disease in the corn. If pastures have been dry and grass is short, cattlemen are anxious to move their cattle into the corn fields and prices for grazing tend to be higher. The more corn left in the field by the grain harvester, the higher the price the corn field commands. If diseases have been prevalent in the corn crop, farmers want residual grain out of the field to minimize infection of the next year's crop and therefore are likely to lower their price. However, there is a pest trade-off. Cattle tend to bring in weed seeds that sprout and grow in the next year's corn crop requiring herbicidal treatments.

Harvesting residue and grazing cattle are not inherently mutually exclusive. Residue collection equipment will harvest only 49 percent of the residue. Much of the residue uncollected will be grain and broken ears of corn which are the most valuable grazing materials. However, time becomes a critical factor. Harvesting typically begins in mid September and snow cover is nearly always an impediment by December 1. Wet falls and early winters, as were the cases in the 1992 harvest season, significantly shorten this window of harvesting opportunity. Because of the short window of opportunity, residue collection would directly be competing with cattle grazing.

The final competitor for corn residue is indirect but very real. Many farmers will be unwilling to allow anyone on their land. After years of labor to get their land just the way they want it, they are not about to let a stranger onto their field to compact the soil, disturb their ridges or leave ruts in their field. Willingness to give up an element of control over the use of their land will depend on the value system of individual farmers and their particular cash flow situation. About five years ago a company asked farmers to collect corn cobs for furfural production. After farmers collected the cobs, the company was to pick them up and pay farmers for their efforts. The cobs were never ~~collected~~ and the farmers were never paid. The memory of that experience was recited to us by many farmers and will affect their willingness to participate in a new venture.

Our previous calculations indicated approximately 5.0 million tons of collectable corn residue in the 25-county area. Removing the most highly erodible land (22.7 percent of the acres) leaves 3.87 tons. If 15 to 30 percent of farmers participate on a two year rotational basis a plant could expect between 290,000 to 580,000 tons of residue. If collection were to be conducted on a three year rotational basis, the number of farmers willing to participate could be expected to increase to 25 to 50 percent. This would result in an annual residue availability of 322,000 to 644,000 tons. The three year rotation would be an easier sell to conservation compliance plans are now managed on a three year average basis.

We can look at cattle grazing and assume that farmers who graze cattle are more likely to consider alternative uses for corn residue than farmers who do not allow grazing. With this assumption, the number of grazed acres may be an indication of potential residue suppliers. Currently some 4.4 million tons of residue are produced on land that is grazed by cattle. If 2.2 million tons of the residue is collectible and if 15 percent of the tonnage could be diverted to fermentation, there would be 330 million tons of residue available for fermentation for a price. Realistically we can expect about 250,000 to 500,000 tons of residue to be available for purchase if the price is right.

PRICE FOR THE FARMER

In 1993, the farmer's perceived value of corn residue is determined by the price paid for alternative uses. In the Kearney area the primary alternative use for residue is grazing.

Rental fees for grazing cattle range from \$5.00 to \$10.00 per acre for the season. As the supply of grazed acres declines, cattlemen will drive up the price to a point which is likely to be about \$10.00 per acre or \$7.00 per ton. Beyond ten dollars per acre, it becomes cheaper for the cattleman to use other feed sources.

Other considerations for the farmer include the cost of replenishing lost soil nutrients. Assuming the farmer is not harvesting residue every year and does not need to replace potassium, replenishing nitrogen and phosphorus will cost about \$0.80 per acre with an applicator cost of at least \$6.00 per acre. This is not a significant impediment. On the other hand, organic matter is not so easily replaced and is a concern for farmers.

Field Operations

In addition to the \$7/ton cost to the ethanol plant of acquiring corn residue from corn growers, is the cost of residue collection, transformation and storage. A general corn residue collection model is illustrated in Figure 3.

Collection Capability

Equipment for making conventional small rectangular "square" bales, large roll bales or large "square" bales is readily available in the Kearney area. Baled corn residue can be handled mechanically. Selection of a field harvest system must consider equipment management issues such as:

1. *Timing of harvest.* The harvest of corn grain must occur before residue collection can begin. Since the residue will be stored before it is used, a time delay between corn harvest and residue collection will be required to allow for additional drying of stalks, especially early in the harvest season.
2. *Field equipment alternatives.* There are a number of options for collecting and packaging corn residue using currently available equipment. Since cost is a

consideration and the actual collection time is only six to eight weeks, it is important to maximize the use of equipment for which there are trained labor and alternative uses. Decisions regarding site of storage, farm verses plant verses off-site locations, are also important.

Timing of Harvest

The window of opportunity for residue collection was estimated using climatic data, Nebraska Agricultural Statistics and Harvest Progress reports. Table 1, documents the dates for corn harvest initiation (10% harvest completion) and culmination (90% harvest completion) for Nebraska Statistical Districts 5, 6 and 8, which are the primary districts of the study area.

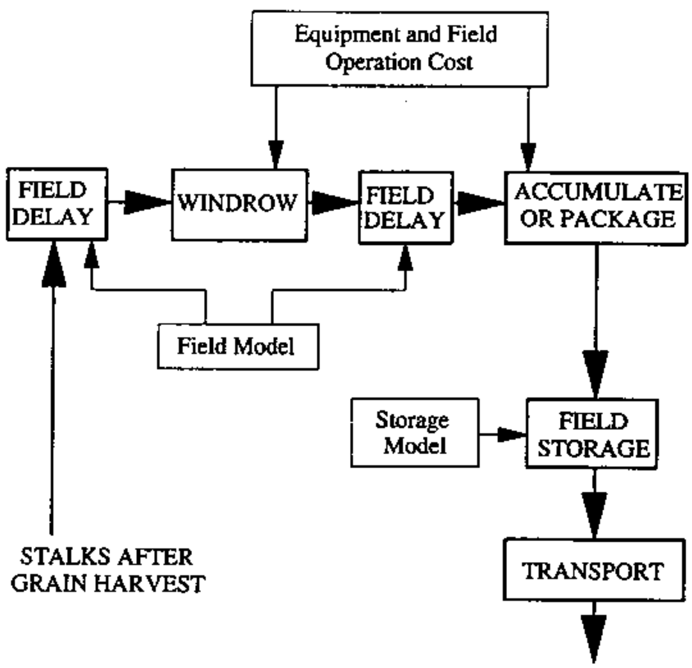


Figure 3. Corn residue collection model

Table 1. Harvest initiation and culmination, Kearney, Nebraska study area.

	Initiation	Culmination
	10% complete	90% complete
Earliest	September 18, 1992	October 24, 1991
Latest	October 11, 1992	December 12, 1992
Average 1982-1991 (10 year ave.)	September 25	November 12
Average 1988-1992 (5 year ave.)	September 24	November 10

Typically, field equipment systems are designed using an 85% to 90% completion probability, meaning that a machinery system will complete an operation within the planned period at least 17 out of 20 years. Figure 4 presents a 90 percent residue collection completion probability curve based on a five-year average of corn harvest data. It is important to remember that initiation of residue harvesting is limited by the progress of grain harvesting, and progress is influenced by weather and the capacity of the residue harvesting system. This curve incorporates some delays for weather and equipment maintenance. The equipment system being recommended by this study is theoretically capable of collecting two million tons of residue between October 8 and December 1.

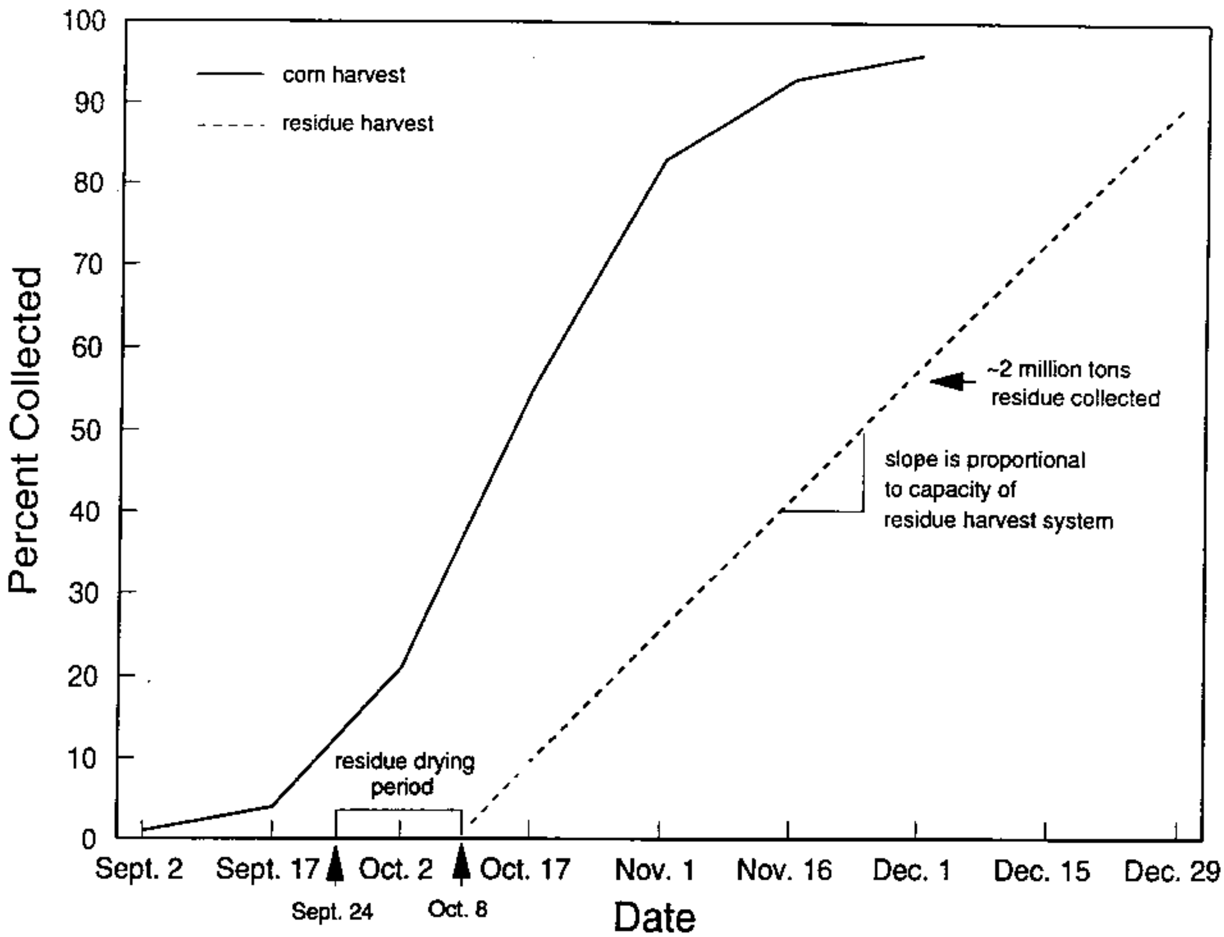


Figure 4. **Theoretical corn and residue harvest schedule based on 1988-1992 % corn harvest completion for statistical districts 5, 6 and 8.**

RESIDUE SYSTEM

The complete system for residue collection and handling was assumed to consist of the following: 1) Multiple field equipment systems to assure completion of baling within a 60-calendar-day window of time; October and November, at a 90% completion probability. 2) Fifty dispersed area storage sites to minimize the risk of fire loss. Only 2% of the annual supply would be concentrated at any one site. Two of these sites would be adjacent to the ethanol plant as an inventory for inclement weather when transport may not be possible. Each area storage site would have an average field-to-storage distance of about 7 miles and would have an average transport distance to the plant of 45 miles. At each area site 6275 roll bales or 7250 rectangular bales would be stored. This number of either type of bale would provide 4,800 tons of residue at the processing plant. 3) Transport of the bales from the area storage sites to the plant site would be conducted 5 days per week year around. During harvest, trucks would be loaded directly from the area sites whenever possible to reduce double handling and avoid conflict with storing the bales. 4) Temporary storage at the ethanol plant would accommodate a small inventory for weekends when trucking would stop. This inventory should also take care of a reduced supply when trucks or other equipment breakdown and delays occur. Storage and preprocessing at the plant were not included in the cost estimation. However, custom rates would indicate a cost of about $7.50 per ton for these activities and the land area required for receiving and temporary storage. The ethanol plant was assumed to operate 350 days per year with 15 days of annual shut-down for maintenance.

No specific plan for weighing the bales across a certified scale has been made. At the area sites, an electronic scale mounted on the unloader/stacker with a computerized data collection system was assumed. This would provide a printout of bale weight to each farmer. Since the scale provides a purely administrative function, the cost of this system was not included in this cost estimate.

Operational Plan for the Residue Harvest and Handling System

Supervisory personnel, maintenance equipment and personnel are essential for an operation of this scope. Details are dependent upon the specific operating plan of the ethanol plant management. The functions could be performed on a contract basis; however, it is more likely that permanent, year-round personnel would fill these roles. Equipment will be needed for these functions. Pick-up trucks for supervisors as well as fuel/repair trucks for maintenance and repair. The cost of actual repairs and maintenance are included in the cost estimates; however, the cost of supervisor and equipment are not. No assumptions were made for this cost element, but it could increase costs by as much as 20%.

Many operational details are dependent upon company policy and are not included in the following performance estimates. It is imperative for a system of this scope that an experienced equipment system manager be employed. An excellent source for such an individual is the sugar beet industry where tremendous quantities of beets are received from farmers, are piled at beet dumps (area storage) and then later transported by semi-trucks to the sugar factory. Knowledge of this system has provided some insights into the operational plan for the residue system.

Equipment for Field Operations

Collecting corn residue requires two primary field operations, windrowing and packaging, as illustrated in Figure 3. Following grain harvest a field delay, at least early in the season is necessary for the residue to dry sufficiently. The residue stalks still attached to the roots and loose stalks, husks and leaves are best assembled into a windrow by a flail unit. These machines are available, but may need to be special ordered because they are not commonly used today. After windrowing, another field delay occurs to sequence machines and to allow further drying before accumulating or packaging the corn residue.

Many options are possible for residue packaging. Small rectangular bales, large round (or roll) bales, large rectangular bales and loose mechanically formed stalks of several sizes are commonly used for hay and residue harvest. Chopping the residue with a forage harvester combined with a cotton module builder (ASAE, 1993a) is another possibility. However, no performance data are available on the durability of a module of corn residue for over-the-road transport. Experience with transporting mechanically formed loose hay stacks would make the approach suspect, especially considering some transport distances may approach 75 miles. For this reason, the module system was not included in the analysis. Research should be concluded to explore the feasibility of this method.

Obvious choices for cost evaluation considering all harvesting, storage, handling and transport operations were the large bale systems. Both large roll bale and large rectangular bale systems are two-pass systems, Table 2. These twine-tied bales are suitable for storage and over-the-road transport with minimal risk of package disintegration during handling.

Because of the advantage from an operations management viewpoint with one tractor and operator being required, an integral flail pickup was also included for analysis. An integral flail pickup unit is commercially available for the roll baler. The width of this pickup is too small for large scale baling operations. After consulting the manufacturer, it was determined that a 10 ft wide pickup was technically feasible. This unit would be integrally mounted on either baler and results in a one-pass system as indicated in Table 2.

Table 2. Equipment for field operations.

System	**Windrower - Roll Baler**	**Windrower - Rectangular Baler**
Two Pass	Windrower - 15 ft Tractor - 46 PTOHP* Bale - 72D** x 62 (in) Tractor - 86 PTOHP	Windrower - 15 ft Tractor - 46 PTOHP Bale - 3 x 4 x 8 (ft) Tractor - 105 PTOHP***
System	**Pickup Roll Baler**	**Pickup Rectangular Baler**
One Pass	Flail Pickup - 10 ft Integral with Roll Baler - 72D x 62 (in) Tractor - 105 PTOHP	Flail Pickup - 10 ft Integral with 3 x 4 x 8 (ft) Rectangular Baler Tractor - 105 PTOHP

*Tractor power rating, power-take-off (PTO)
**Diameter
***Tractor size is required for stability

FIELD COLLECTION COSTS

Five major factors are involved in estimating the economic performance of the corn residue field harvest system. These are:

1. The economic environment. Included are the current interest rates for taxes and insurance, and the prices of inputs such as fuel, lubricants and labor.
2. The machine characteristics. Machine size or width, tractor-machine match, fuel consumption, and repair and maintenance costs are examples of machine characteristics.
3. The operating parameters. Major parameters are field speed, field time efficiency and field time per day. Machine productivity is the combination of machine characteristics and operating parameters.
4. Crop or material characteristics. Yield of corn residue, moisture content and crop or material condition are examples.
5. Schedule and timeliness. Windows of time available for an operation, weather-crop-soil interaction and field losses attributable to machinery size are examples.

In this report, operation is the designation given to the basic task performed by a machine. In the field collection of corn residue, windrowing and baling or combined windrow-baling are the basic field operations.

COST OF FIELD OPERATIONS

Costs of using machines were calculated using the approximate average annual cost approach which is most commonly used in estimating farm machine costs. The general procedures outlined in Agricultural Machinery Management EP 496.1 MAR 93 (ASAE, 1993b) and data from Agricultural Machinery Management Data D497.1 MAR 93 (ASAE, 1993c) have been used. Fuel use by tractors was based upon estimated energy requirements for operations (Bowers, 1992) and the fuel-consumption of a tractor related to the equivalent power-take-off power load. This information was obtained from University of Nebraska Tractor Test Reports. Details of the approximate average annual cost model are given in Appendix VI. This cost model was programmed for computation by personal computer.

Cost estimates were made for the two-pass systems assuming a 1-ton residue yield, Table 3. Losses from (1) the field into area storage, (2) area storage and handling and (3) transport to the plant were estimated to be 3%, 4% and 3% for roll bales and 2%, 3% and 2% for rectangular bales, respectively. An average roll bale delivered to the plant was estimated to weigh 1,530 pounds (0.77 ton). A corresponding rectangular bale was estimated to weigh 1,325 pounds (0.66 ton).

Table 3. **Windrow and bale systems cost performance.**

		Roll Bale (a)	Large Bale (b)
RESIDUE DATA			
Yield t/A		1.0	1.0
OPERATING DATA			
Windrower:	Energy, HP-h/A	10.5	10.5
	Field speed, mph	6.5	6.5
Baler:	Energy, HP-h/A	6.0	6.0
	Field speed, mph	6.0	7.0
	Time utilization	0.75	0.75
	Acres (A)	2,400	3,000
Tons collected		2,400	3,000
OPERATING RESULTS			
Windrower:	Acres/hour	10.64	10.64
	Field hours	225.6	282.1
	Calendar days	37.6	47.0
Baler:	Acres/hour	7.09	8.27
	Field hours	338.5	362.6
	Calendar days	56.4	60.4
Tons collected		2,400	3,000
COST			
$/A		11.14*	13.78*
$/ton*		11.14	13.78
FUEL, DIESEL			
Total gallons		2,409	3,311
Gallons/ton		1.00	1.10

(a) Table 1 (b) Table 2 *At harvest

Table 4. Pickup-bale systems cost performance.

	Pickup Roll Bale (a)				Pickup Large Bale (b)			
RESIDUE DATA								
Yield t/A	1.0	1.0	1.25	1.5	1.0	1.0	1.25	1.5
OPERATING DATA								
Energy, PH-h/A	10.4	10.4	11.1	11.7	10.4	10.4	11.1	11.7
Time Utilization	0.75	0.75	0.75	0.75	.075	0.75	0.75	0.75
Acres (A)	2000	1650	1650	1650	2300	1900	1900	1900
Field speed, mph	6.0	6.0	5.5	5.0	7.0	7.0	6.5	6.0
OPERATING RESULTS								
A/h	4.49	4.49	4.12	3.74	5.24	5.24	4.87	4.49
Field hours	445.3	367.4	400.8	440.9	439.0	362.6	390.5	423.1
Calendar days	74.2	61.2	66.8	73.5	73.2	60.4	65.1	70.5
Tons collected	2000	1650	2063	2475	2300	1900	2375	2850
COST								
$/A	14.57	15.49	16.40	17.51	17.00	17.73	18.74	19.95
$/ton*	14.57	15.49	13.12	11.67	17.00	17.73	14.99	13.30
FUEL, DIESEL								
Total gallons	1403	1157	1243	1328	1960	1620	1737	1857
Gallons/ton	0.70	0.70	0.60	0.54	0.85	0.85	0.73	0.65

(a) Table 1 (b) Table 2 *At harvest

Equipment for Handling and Transport

Following completion of residue baling, the bales are collected, loaded and transported to the area storage sites, Figure 6. These operations were combined in the analysis and assumed to be accomplished by custom operators at typical custom rates. This approach was assumed in order to minimize the operations management activities of the ethanol firm.

At area storage sites, handling the bales begins by unloading the bales from the trucks of the custom operators, weighing the bales and then moving and stacking the bales. Unloading from the trucks and placing in stacks were accomplished using a telescopic boom unloader which is described in Table 5.

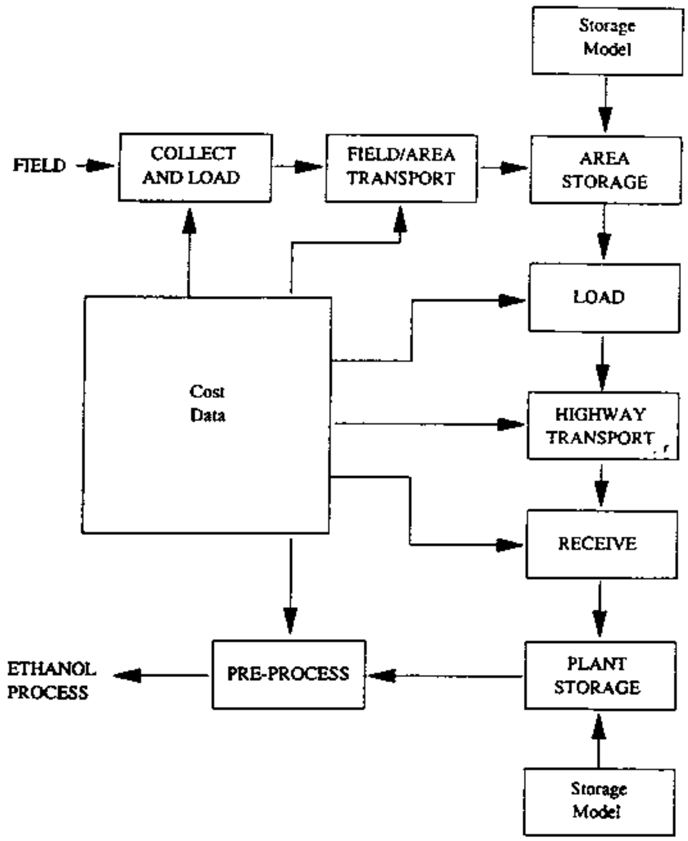


Figure 5. Transport to ethanol plant.

Table 5. Bale loading and transport.

Loader	A four-wheel drive 102 HP loader-tractor with a telescopic boom, 18 foot reach and a 19 foot lift height. Will stack 3 x 4 x 8 foot bales five high.
Transport	Flat bed, 44 feet long. Capacity 33, 3 x 4 x 8 bales or 26 72D x 62 (in) roll bales.

Collecting, loading and transporting the bales to the area storage sites can be accomplished in many ways. To minimize the operations management activities, custom operators at the prevailing Nebraska rates were used for cost estimations.

Following storage, the bales are loaded by the same loader onto semi-trailers for transport to the ethanol plant. Each area storage site requires one loader. In order to fulfill the needs of the ethanol plant of 4,800 tons of residue per day, 1,508 rectangular or 1,467 roll bales per 5-day transport work week are required. During a 75-day collection-stacking period, the harvest period plus 15 days, two extra loaders are used to transfer bales to the semi-trailers for movement of bales to the ethanol plant. These two loaders will rotate to various sites and will avoid conflicts between receiving, stacking and loading bales. A total of 52 loaders at $65,000 each are required and will average about 200 hours of operation per year.

Transport is a major activity. Each working day 57 loads of roll bales or 46 loads of rectangular bales are required per 5-day work week. To provide this capacity, 15 tractor-semitrailers are needed for roll bale transport or 12 units for rectangular bales. On the average, each truck will make 4 trips per day. Transport costs were figured at a rate of $0.09/ton mile one-way when loaded to the legal limit. This total cost per trip was then related to the load size delivered to the plant. For roll bales 19.89 tons/load was the average for 26 bales and 21.97 tons/load was the average for 33 rectangular bales. Roll bale transport requires that 11,584 over-the-highway trips be made with <u>wide loads</u>. Because of this situation, a loaded average speed of 45 miles per hour, 5 miles per hour less than for the rectangular bale loads which are not over width, was assumed. This many "wide load" trips needs further investigation in terms of time assumptions, legal requirements and negative public opinion.

Two loaders identical to those used at the area storage sites, Table 5, were anticipated for unloading the trucks at the plant site. When unloading the rectangular bales, the annual operation was estimated at 1,317 hours per loader. For roll bales, 1,280 hours per year per loader was estimated.

SUMMARY SYSTEM COSTS

Four different systems were evaluated. All cost estimates have been adjusted to reflect the cost per ton to deliver to the plant 240,000 tons of residue per year. For the roll bale systems, a total of 266,667 tons must be baled to allow for the estimated storage and handling losses of 10%. A total of 258,064 tons must be harvested to compensate for the estimated 7% losses when using rectangular bales.

Two-Pass Windrowing and Roll Baling

The total cost delivered to the plant was estimated to be $27.43/delivered ton with a yield of 1 ton per acre, Table 6. This cost reflects the lower investment in smaller tractors needed for the roll baler, Table 1. An equipment complement consisting of 111-46 PTOHP tractors, 111-86 PTOHP tractors, 111 windrowers and 111 roll balers is needed.

Two-Pass Windrowing and Rectangular Baling

A delivered cost of $28.81/ton was estimated for the two-pass rectangular baling system with a 1 ton yield, Table 7. A 3 x 4 x 8 baler requires a large tractor for stability. This, combined with the higher cost of the baler, increases the fixed costs compared to the roll baler. This is not offset by the increased operating speed and reduced complement size. A total of 86-46 PTOHP tractors, 86-105 PTOHP tractors, 86 windrowers and 86 rectangular balers are needed for the complete residue system.

One-Pass Pickup Roll Baler

With a 1-ton per acre yield, the delivered cost for the one-pass pickup baler system was estimated at $32.17 per ton, Table 7. The equipment implement needed was 162 pickup roll balers and 105 PTOHP tractors. Even with fewer equipment units and operators than the two-pass roll baling system, the cost increased for the one-pass system. This is the result of decreased capacity per pickup baler and larger tractors to power these balers.

As yield increases, the number of pickup balers and tractors decrease, Table 7. At 1-1/4 tons per acre, the cost is estimated to be $28.56 with 129 baler and tractor units. When residue yield is 1-1/2 tons per acre, the number of equipment units drops to 107 and the estimated cost is $26.96 per ton. It must be noted that the 1650 acres per baler was not changed in the analysis. As residue yield increased, field speed decreased and the calendar time to complete the operation was 65.1 and 70.5 calendar days, respectively, for the 1-1/4 and 1-1/2 ton per acre yields.

One-Pass Pickup Rectangular Bales

Cost estimates per delivered ton for the rectangular one-pass baler system were $33.05, $30.11 and $28.25 per delivered ton for residue yields of 1, 1-1/4 and 1-1/2 tons per acre, Table 8. The equipment complement was 135-105 PTOHP tractors and pickup balers when the yield was 1 ton per acre. For yields of 1.25 and 1.50 per acre, 109 and 91 units, respectively, are needed.

Added Costs

In addition to the cost of collecting, handling and transporting residue, the cost of preprocessing must also be added. Using farm custom rates for tub grinders, size reduction will cost about $7.50 per ton. The cost of the purchase of the residue from the farmer also and a cost for fertilizer and application must be added to offset the loss of soil nutrients when residue is removed.

Table 6. Two pass system summary.

Field Residue Yield, 1.0 tons/acre	Cost Per Delivered Ton	
	Roll Bale	Rectangular Bale
Field Harvest	$12.38	$14.82
Field to Area Storage	4.12	3.95
Unload and Stack	1.48	1.45
Area Storage	0.36	0.21
Load for Transport	1.48	1.45
Highway Transport	7.33	6.64
Unload at Plant	0.28	0.29
TOTAL	$27.43	$28.81

Table 7. One pass system summary.

Field Residue Yield, tons/acre	Cost Per Delivered ton		
	1.0	1.25	1.50
Field Harvest, Pickup Roll Baler	$17.21	$14.57	$12.97
Field to Area Storage	4.12	4.12	4.12
Unload and Stack	1.48	1.48	1.48
Area Storage	0.36	0.36	0.36
Load for Transport	1.48	1.48	1.48
Highway Transport	7.33	7.33	7.33
Unload at Plant	0.28	0.28	0.28
TOTAL	$32.17	$28.56	$26.96

Table 8. One pass system summary.

	Cost Per Delivered ton		
Field Residue Yield, tons/acre	**1.0**	**1-1/4**	**1-1/2**
Field Harvest, 3 x 4 x 8 Baler	$19.06	$16.12	$14.30
Field to Area Storage	3.95	3.95	3.95
Unload and Stack	1.45	1.45	1.45
Area Storage	0.21	0.21	0.21
Load for Transport	1.45	1.45	1.45
Highway Transport	6.64	6.64	6.64
Unload at Plant	0.29	0.29	0.29
TOTAL	$33.05	$30.11	$28.29

FIELD OPERATIONS CONCLUSIONS

A low cost of $27.43 per delivered ton with the two-pass roll bale system at a yield of 1 ton per acre was estimated. This system requires 222 tractors, 111 windrowers and 111 balers. Supervisory and service personnel and the accompanying vehicles and equipment have not been included. Various management schemes need to be proposed and evaluated for cost effectiveness. On the other hand, a one-pass rectangular bale system at a 1 ton per acre yield had an estimated cost of $33.05/delivered ton. This system only required 91 tractors and 91 pickup balers. This is a significant reduction in equipment units and thus will require less supervisors and service personnel. These aspects need to be included in the cost comparisons before final decisions are made.

Many other options could be evaluated. For example, the 3 x 4 x 8 baler can be equipped with a 3 bale accumulator. This would reduce the bale collection-assembly time and could lower costs. Additional data are needed for such an analysis to be made.

Perhaps the greatest need for improvement is in the estimates of handling and storage losses. Only experimental estimates have been made and quantitative data are needed for definitive cost estimations.

Storage Issues

If corn residue, collected during October and November, is the only supply of cellulose for a fermentation facility, careful attention will need to be given to the issue of storage. Selection of storage type must consider the extent of degradation of lignocellulosic biomass prior to processing by the fermentation facility. Factors that need to be understood include:

1. the extent of residue deterioration as a function of time and temperature,
2. the types of organisms most commonly found in rotting corn residue bales,
3. the effect of moisture on deterioration,
4. the type of deterioration, i.e. cellulose, hemicellulose or lignin degradation,
5. the location of decay, top vs. center vs. exterior vs. ground contact, and
6. the heat transfer characteristics of corn residue bales.

It is our understanding that a research team in Colorado is involved in a project addressing some of these concerns. We have reasonable hopes of collecting at least sufficient corn residue for a fermentation plant, but if a significant amount of the residue is going to degrade in storage, it will be necessary to collect excess residue to compensate for the loss and the input cost of residue will correlate with the extent of degradation. This significantly impacts the economic feasibility of a corn residue to ethanol venture.

CONCLUSIONS

There is sufficient corn residue grown in the Kearney, Nebraska area to supply an ethanol plant with 240,000 tons of corn residue per year. The equipment required to harvest and package the residue are commercially available using special ordering of the flail pick-up option is desired.

Major impediments to residue collection arise from its dependence on the conclusion of grain harvesting, a small window of opportunity due to the onset of winter, and restrictions on residue harvest due to soil conservation restrictions. Other considerations include the past negative experiences of corn growers with residue collection efforts and a hesitancy to allow others onto their land.

The approximate cost of corn residue is summarized in Table 9. This cost estimate does not include the cost of administration and supervision of residue collection. This is a critical element due to the short period of time available for harvesting residue.

The cost estimates provided in this report must be considered preliminary because residue quality standards and the effects of storage on residue quality were unavailable to the investigators. If quality standards are tight and/or if there is significant residue deterioration during storage, the cost of residue would increase significantly and the determination of supply sufficiency would need to be re-evaluated.

Table 9. Cost of Corn Residue in Kearney, NE Area-1993

Cost Variables	**$/ton**
Purchase price to corn growers	$7-10
Compensation for loss of soil nutrients	7-8
Harvest, storage and transportation	27-32
TOTAL	$41-50
Supervision/Administration (10-20%)*	

*Dependent upon time policies, benefits, etc.

APPENDICES

APPENDIX I
Task 32

State Project Support,
Nebraska Corn Stover Removal Analysis
Contract No. DE-AC65-90WA05637
J.L. Butler, P.E.

Recent developments (Barrier et al. 1986; Broder et al. 1992; Spindler et al. 1989) in the acid hydrolysis process to convert cellulose and hemicellulose to glucose and xylose, which may then be fermented to ethanol, have resulted in increased interest in the use of corn stover as an energy crop. Stover is the above ground portion of the corn plant, other than grain, and consists of stalk (including tassel), leaves, cob, husk (and silks). With present practices, this stover is usually left in the field following combine harvesting of the grain, and in this report will be referred to as residue. In some areas, the residue is grazed. Even when grazed most of the fertilizer and organic value of the residue is returned to the soil. The farmer recognizes that the residue has a monetary value, and if residue is to be removed from the field, the farmer must be paid this value plus some profit. At the same time, the residue must be priced low enough to be an attractive feedstock for ethanol production. The amount of residue removed must be limited so as to leave an adequate amount to protect against erosion of the soil by water or wind. These required amounts of residue will vary with location, soil type and topography. Larson (1978) recommended that a minimum of one ton/acre of corn residue to be left on erosive soils. In addition to these considerations, a sufficient quantity of the residue must be available within a reasonably short haul of the processing plant which will convert the residue into alcohol. Because of the low specific density of this residue, it is likely that some form of densification must be done prior to transporting.

Using a radius (modified) of 70 miles, the area around Kearney, Nebraska has 25 counties which collectively grow more than three million acres of corn annually. Information provided by Sayler (1992) shows that the average yield of grain per acre in these 25 counties is about 140 bushels. The amount of corn residue produced in making a bushel of corn will vary depending not only upon variety, but also on the environmental factors during the growing season. For example, moisture deficiency during the growing season will disproportionally reduce the grain yield compared to stover. Regardless of the amount of residue produced, the farmer must be willing to have it removed. This willingness is dependent upon several factors, only one of which is price.

In July of 1992, three days were spent with the University of Nebraska Industrial Agricultural Products Center personnel discussing the project and interviewing farmers and District Extension Agents (see attached list) The visits were very informative because these people are the key to the ultimate success of an enterprise using corn crop residue from this area. Discussions with these people brought forth the following:

- Equipment associated with residue harvest must fit the existing (30 or 36 inch) rows.
- Selling price must be high enough to cover all costs, including nutrients removed, plus some profit for the farmer.
- Estimates of number of farmers participating, assuming above conditions are met, ranged from 20-50%. The number would be expected to increase in subsequent years, if the enterprise is successful.
- Most corn-growing farmers in the area do not possess equipment suitable for harvesting the residue. Thus, they would participate with the use of custom operators.

- o Most producers would want the collection complete and the equipment out of the field before the normal fall rains would cause the equipment to leave ruts in the field. This means the collection should be completed and the residue removed by mid-November at the latest.
- o In some parts of this area, especially the western part, grazing of the residue by cattle is currently practiced. This practice eliminates the problem of germinating ears of corn causing problems in the crop the subsequent year and leaves most of the nutrients in the field. Therefore, a good profit incentive may be required in this part of the area.
- o The normal hay dehydration season ends in mid-October. The harvesting and transporting equipment used in these operations is high-capacity, heavy duty and might be modified to fit the row patterns of corn. This is a potential source for custom operators because most of the crews normally head for the unemployment office once the hay dehydration season ends.

Residue potentially available

Ayres (1973) developed an equation based on corn yield. This equation states that the residue from corn grain (in pounds per acre) = Yield (in bu/acre) x 22.61 + 2576. Using this equation the grain:residue ratio of 1:1, which is frequently used, is reached with a yield of approximately 80 bu/acre. With a yield of 150 bu/acre, the equation would yield 8400 pounds of grain and 5967 pounds of residue for a ratio of 58:42.

Claar and Marley (1981) referring to earlier work (Buchele and Marley 1978), stated that in a typical year a central Iowa farm producing 7.22 tons of corn grain per hectare (115 bu/acre @ 15.5% MCWB) would produce 7175 kg/ha (6400 lb/acre) of residue on a dry weight basis. This is almost a 1:1 ratio of grain:residue. The residue consisted of 54% stalk, 21% cobs, 13% husks and 12% leaves. Using the formula by Ayres, the residue yield should have been only 5176 pounds/acre. However, in other tests reported by Claar and Marley (1981), the total corn residue from a field yielding 170 bu/acre was only 7160 lb/acre. This is a grain:residue ratio of 57:43. The Ayres equation would project a yield of only 6400 lb/acre, or 760 lb/acre less.

Peart (1981) stated that corn yielding 7000 kg/ha (125 bu/acre) produced 1250 pounds of cob and 5750 pounds of other residue, for a total residue of 7000 pounds/acre--a grain:residue ratio of 1:1. The Ayres formula would produce a residue yield of 5400 pounds/acre, or 1600 lb/acre less.

Johnson (1985) states that producers and retailers of seed corn often recommend those hybrids having the highest ratio of grain to stalk for silage production. In testing 13 hybrids, he found that the grain:stover ratio varied from a high of 53:47 to a low of 40:60. Five of the thirteen had less than 50 percent stover and eight had fifty percent or more stover. In these tests, the stalk was cut approximately 4 inches above the ground.

Gipson (1991) reported that Pioneer 3154 (194.4 bu/acre) and DeKalb 689 (173.5 bu/acre) were the two top yielding corn hybrids grown at the Georgia mountain station. These midseason hybrids (63 days from planting to mid-silk) were planted May 14 and harvested October 21 and are probably similar in characteristics to those grown in the area around Kearney. On a dry matter basis, they had grain:stover ratios of 49:51 and 52:48 respectively when harvested as silage.

Richey (1982) did a study of harvesting corn stover for energy. He assumed a grain:residue ratio of 1:1. The tests using a windrower with a flail pickup following a combine which harvested 140 bu/acre resulted in an average if 2.1 tons/acre of residue being placed in the windrow. The remaining material was picked up by hand and averaged 1 ton/acre. Based on the windrowed and gleaned samples, the residue yield was 3.1 tons/acre. The theoretical residue yield (based on a 1:1 ratio) should have been 3.9 tons/acre. A considerable portion of the difference was likely due to the breaking of the stover into small pieces, which blew away as dust or were too small to be picked up, by the combined operations of harvesting the grain and then windrowing the residue. It is also likely that the residue yield was less than the grain yield. Based on the total amount of residue which could be collected by machine and by hand, the grain:residue ratio was 557:443.

On the basis of the above research and without specific data for the area, it appears that a grain:residue ratio of 56:44 would be a conservative ratio to use in calculating the residue potentially available to harvest. Using this ratio, the 140 bu/acre grain yield would produce a potentially harvestable residue yield of 6200 lb/acre.

Grain Harvesting Process

In the corn harvesting, or combining, operation the stalk and a significant amount of husk is normally pulled down through the snapping rolls with the ear, containing some husk,entering the combine. Since the stalk is usually still anchored to the soil to some degree, most of this residue falls on the row. A significant amount of it does, however, fall within the middles where it can be run over by either combine or grain hauling equipment and pressed into the soil. The ear and remaining husk go through the combine where the grain is removed from the cob. The amount of cob breakage during the removal of the grain from the cob is affected by the moisture content of the cob and grain, the clearance between the cylinder and concave, and the cylinder speed, the cob is broken to different degrees into small pieces. Following the removal of the grain from the cob, the grain is separated from the pieces of cob, husk and other plant parts. Subsequent to the separation, the grain is elevated into the grain tank and the cob and other plant parts are discharged onto the ground.

With the settings normally used, the cob is broken into pieces which cannot be picked up with salvaging equipment, unless these pieces are still attached to the husk, or rest on large sections of husk or are caught within the stalk mass. The residue which is pressed into the soil by the wheels of the combine and grain hauling equipment is very difficult to remove with residue salvaging equipment. A 6-row combine, depending upon row spacing and amount of residue falling in the wheel path, could be expected to press 15-20 percent of the residue into the soil and complicate further removal. Since the grain hauling equipment, for the most part will follow the same route, the amount of residue compacted by this equipment would probably press only about 10% more residue into the soil. Based on this it appears that, with six-row equipment, as much as 30% of the residue, in addition to the pieces of cob will be difficult to salvage.

Residue Harvesting

Since Buchele (1978) found that the cob made up 21 percent of the residue, and this portion will be difficult to retrieve once it is dropped on the ground, it probably should be evaluated for separate collection.

Liljedahl et al (1983) reported a cob salvaging system which collected the material falling off the straw walker of the combine and blew it into a trailing wagon. This device collected about 80% of the available cobs, with cobs making up about 93% of the total residue collected. One wagon load of cob mixture corresponded to 4-5 combine hopper loads of grain. Smith et al. (1984) found that the cob residue, as a percent of the grain yield, ranged from 14% in corn yielding 116 bu/acre to 17% in corn yielding 92 bu/acre. By reducing the concave front clearance and increasing cylinder speed to increase cob breakup, about 50% of the cobs could be collected without severe grain damage.

Morey et al. (1984) reduced concave clearance and opened the sieves so that broken cobs and shelled corn would be collected in the grain tank. This cob and grain mixture is transported to the drying facility so that a separate hauling system is not needed for the cobs. Because of the lower density of cobs, compared with grain, the bulk density of the corncob-grain mixture was only about 70 percent of that of the grain alone. Consequently, the combine grain tank would hold only about 70% as much grain as it would of the grain alone. The actual unloading time for unloading the mixture was increased by 9% compared to shelled corn alone. Approximately 90% of the cobs were recovered by this system.

Based on the data reported above, it appears that the yield of corncobs will range from about 14% to 21% of the grain yield. If we assume an average of 16%, the 140 bushel yield for the area being considered would produce about 1250 pounds of cob per acre. The systems above should collect from 625 to 1125 pounds of cob per acre.

Richey et al. (1982) used a windrower with a flail pickup to cut and windrow the residue following a six-row combine corn harvester. A 4.3 m (14 ft.) wide flail rotor cut and lifted the residue into a transverse auger which deposited the windrow in the center of the cut. It was able to cut six 76 cm (30 inch) rows for an effective width of 4.6 m (15 ft). The rotor was operated to produce a knife tip speed of about 113 ft/s rather than the normal speed of about 125 ft/s. The slower speed reduced both the shredding action and energy requirement. The longer pieces of stover bind together better and help to make a more durable bale. He found that, although the field was reasonably level, it was necessary to cut about 3 inches above the ground to avoid picking up soil. Richey believed that the amount picked up by this harvester would be less if the corn were ridge-planted. He found that this machine placed about 2.1 tons/acre in the windrow and left about 1 ton/acre. About two-thirds of the available material was thus placed in the windrow although the actual amount varied from 82 to 34 percent depending primarily on the material which had been trampled by the combine and grain hauling equipment. Both big roll balers and stack wagons were used to pick up and consolidate the residue from the windrow. These machines actually placed in the bale or stack only about one ton of residue per acre-only about half of that windrowed. Richey explained that much fine material was deposited under the baler during the twine tying operation (which required about 12 turns instead of the usual six.). The open chain and crossbar construction of the baler perhaps also contributed to these losses. Much dust was generated by each of the machines and this is likely a significant source of the losses. Although the residue yields were about 3.1 tons/acre, only about one ton per acre was actually packaged, meaning that 2.1 tons per acre were left in the field.

Claar et al. (1981) evaluated corn residue removal by: 1) corncobs only removed during the corn combining operation with a cob residue collector, 2) stack wagon, set to remove the maximum amount (100%) of residue by allowing the pickup unit to ride on the ground following combining and without additional preparation and, 3) stack wagon (50% removal rate), with the pickup unit set approximately four inches above the ground after the combine operation without any further preparation of the residue. The cob residue collector salvaged 1485 lb/acre, the maximum removal rate with the stack wagon yielded 3510 lb/acre and the 50% removal rate with the stack wagon harvested 2960 lb/acre of residue. Based on the control plot residue yield (7160 lb/ar) these three methods collected 20%, 49% and 41%, respectively. Claar stated that because of the ridge tillage practice, it was impossible with this equipment to remove all that portion of the residue which was in the furrow. When this is considered, his maximum removal rate is not too far out of line with that found by Richey in using the flail windrower where ridge tillage was not practiced.

Claar et al. also investigated the energy required to collect the corn residue by four different methods. These were: 1) corncob residue collector, 2) stack wagon, 3) large round baler and, 4) rectangular baler. The latter three methods were tested at the maximum and 50% residue removal conditions described in the above paragraph. The removal rates used in this analysis are rounded to the closest ton (based on above) for the maximum and 50% removal rates. For the corncob collector, the yield used is almost 50% more than that stated in the above. The operational energy data are presented in Table 1.

Based on the above data, getting corncobs to the roadside would require the least energy of the systems evaluated. The data also show that the energy costs go up as the amount of residue collected per acre decreases. It should also be remembered that, even though the residue was more than three tons per acre, the stack wagon was able to remove less than two tons when 100% removal was attempted. The data also indicate that handling the rectangular bales (35 bales/ton) required the same energy as handling the large round bales. Although it was not stated, this could be possible if a bale accumulator and retriever were used. This would make the small rectangular bales approach large rectangular bales in handling efficiency.

Jenkins (1985) found that a baler producing large rectangular bales of rice straw had a measured capacity of 3.6 ton/hr, compared with 5.4 ton/hr for a large round baler operating under the same conditions. In these comparisons, it was noted that the capacity would probably be increased by increasing operator experience with the large rectangular bale. The greatest difference which he found was that the density and geometry of the rectangular bale allowed the loading of twenty-eight bales on the highway transport trucks for a full truck payload of 24 tons. By contrast, he stated that the 1.5 m (5 ft) wide large round bale could be loaded only to 30% of truck payload. Using a 1.2 m (4 ft) wide large round bale to allow the bale to be stacked two-wide on the truck bed would increase the truck payload to 50-65% of full capacity. In an earlier study Dobie (1977) reported tests with three-wire balers, large round balers, stack wagons, field cubers, and buckrakes for collecting and handling rice straw. For a haul distance of 10 miles, he concluded that a system using a 4 ft wide bale would have the lowest total delivered cost. These results would probably translate to corn residue, and on the basis of this and the work reported by Jenkins, we assume that the large rectangular bale would have the lowest transportation cost.

In transporting cotton from the field to the gin (as much as 30 miles or more) modules are used. These are built by dumping the cotton, as harvested, from the cotton picker into a large box (to make a module 7.5 ft wide by 30 ft long and 7-8 ft high) where it is compacted by hydraulic pressure. Once the is formed, the module builder is moved and the process is repeated. The module, weighing about 10 tons (density about 11-12 lb/ft^3), is loaded onto a self-loading trailer for transport to the gin. No data on using the module builder to pack corn residue, but the resulting module should be as dense as the cotton module at the very least. Again, without data, assume that the energy for forming the module would be about one-half the energy for baling (since the unit is stationary) and that the energy required by the self-loading trailer would be about one half of the handling energy for bales as found in Table 1. The energy for a system using a module builder will be discussed later.

The energy for truck transportation will vary widely, depending upon topography,road conditions, traffic and percent of payload. Fluck (1992) lists a range of 0.5-4.5 MJ per ton km, with an average of 1.8 MJ per ton km. Expressed in Btu per ton mile, the range is from about 475-4300 Btu per ton mile with an average of 1700 Btu per ton mile.

The 70 mile radius selected for this study would probably have a median haul distance of about 45 miles (since all roads would not be a straight line from the field to the processing plant). The possibility of back-haul is slight and an empty return should be considered. If we assume an 12 ton hauling unit (tractor and 36 ft.trailer) and a hauling distance of 45 miles, 918,000 Btu must be added to the transportation energy for each load hauled. This unit would be capable of hauling 18 4'x 4'x 8' bales, with an assumed weight of one ton each total weight 18 tons. For the 5 ft diameter by 5 ft long bales, the capacity would be 13 bales each with an assumed weight of 1000 pounds-6.5 tons total. Two hundred and forty conventional bales, weighing 90 lb each would be considered a load. The total weight of these would be 10.8 tons.

Residue harvesting systems

Based on the equipment studied, the recommended systems for harvesting corn residue would all begin with a flail type windrower to place the residue in a windrow for picking up. Richey recommended that the stalks be cut about three inches above the soil. For ridge tilled operations, the flails over the row should be shortened so that the three inch cutting height could be maintained while allowing better pickup of the residue between the rows without getting an excessive amount of dirt mixed with the residue.

The use of a corncob saver, even though the energy requirements look good, will not be considered because its use would slow down the corn combining operation and the farmers would not accept it unless it returned more profit than appears possible.

The stack wagon appears useable only for very short hauls and it is not used in these possible systems.

In order to estimate the energy requirements for these systems the data presented by Bowers (1992) will be used. It must be understood that the values will vary widely depending upon many variables. It is believed, however, that the average values will be an effective guide in determining the energy requirements for delivering the corn residue to the roadside. The values to be used are:

Operation	Fuel Consumption	
	L/ha	Btu/acre
Windrower	6.17	96600
Baler, rectangle	4.21	65920
Baler, large round	7.48	117125
Forage harvester	17.49	273865
Shred cornstalks	5.61	87850
*Stacking	7.95	124500
**Load (per ton)	1.22	44550

*Data from Shelton et at.(1981)
**Data from Jenkins et al. (1986)

Hauling hay is listed as requiring 0.35L per ton km which is equivalent to 21660 Btu per mile. Distance to roadside assumed to be 0.5 mi. The stacking energy for the rectangular bales is assumed to include the hauling to roadside. For the system using the forage harvester, it is assumed that the knives will be set to give the maximum length of cut and, since the stalks are dry, the average energy for this operation will be assumed at the average of the forage harvester and shredding cornstalks, i.e., 11.55L/ha or 180850 Btu per acre.

Based on the above data and assumptions, the systems and energy requirements are shown in Table 2.

Evaluation

These systems are based on the assumption that one ton of residue per acre will be collected. Richey (1982) was able to place two tons, from a potential three ton yield, into the windrow. From this, he gathered 1.1 tons/acre , getting about the same results with the stack wagon as with the baler. Thus, with conventional equipment, it should be possible to harvest at least one ton of residue per acre in the Kearney area. Since the flail windrower put more than 2 tons/acre in the windrow, a logical improvement would be to feed directly from the windrower into the compacting machine. For the forage harvester, this could be readily accomplished by mounting a flail pickup on the machine. Somewhat more work would be

required to put the windrower on the baling machines, however, it would not be too difficult. By utilizing this approach, it appears that the yield could be easily doubled and still leave the minimum of one ton of residue per acre which Larson recommended.
Doubling the amount collected per acre would reduce all energy inputs except the transportation energy, which is the largest component.

The energy requirement for the large round bale appears to be the greatest followed by the module. The large rectangular bale appears to require the least energy, followed by the conventional rectangular bale. Even though the module appears to require more energy than either of the baling systems, it should be evaluated along with the other three systems. The advantage which it has over the other methods is that a large volume can be covered with a minimum of time and expense. Cotton modules, with cover, may stay out for months under conditions potentially more degrading than those expected in the Kearney area.

Broder et al. (1992) states that one ton of corn stover is expected to yield about 72 gallons of ethanol/ton. Barrier et al.(1986) calculates that the energy consumed by the acid hydrolysis is about 20000 Btu/gallon. Foutch, et al. (1981) states that an energy balance of the ethanol process shows that the heat required for the ethanol distillation can be supplied from the solids remaining after hydrolysis.

On the basis of this information and the energy requirements per ton (neglecting any fertilizer value which the residue had), one ton of stover, converted to alcohol by the acid hydrolysis process would yield 6,408,000 Btu. Subtracting the energy required for hydrolysis (20000 x 72) would leave 4,968,000 Btu. Subtracting even the most energy intensive harvesting and transporting process of 628,000 Btu/ton would still leave 4,339,935 Btu of energy.

Summary

This review shows that by using equipment readily available, it is possible to harvest a minimum of one ton of residue per acre. With modifications, it is believed that the amount can be doubled to two tons/acre, which would still allow enough remaining residue to protect the soil against water and wind erosion. The energy balance, neglecting invested energy, shows that a net energy equivalent of about 48 gallons of ethanol should be produced for each ton of corn stover processed.

The recent extension of the federal tax credit of 52 cents per gallon to the year 2000 and the extension the Nebraska producer incentive program of 20 cents per gallon and creation of a 50 cent/gallon ETBE credit should provide incentive for the use of this residue.

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Table 1. Energy Requirements For Residue Collection

	Max. Removal 2 ton/acre			50% Removal Rate 1 ton/acre			Corncob Removal 1.1 ton/acre
	Stk. Wagon	L.R. Bale	Rect. Bale	Stk. Wagon	L.R. Bale	Rect. Bale	Chaff Saver
	Energy Required			Energy Required			Energy Required
Operation	Btu/ton			Btu/ton			Btu/ton
Preparation		17125[1]	34250[2]		25690	51375	
Harvesting	30825	30825	30825	46240	46240	46240	13700[3]
Hauling[4]	13700	13700	13700	13700	13700	13700	21920
Handling	13700	13700	13700	13700	13700	13700	15000
Processing[5]	30825	30825	30825	30825	30825	30825	13700
Total	89049	106125	123300	104465	130155	155840	64320

Footnotes:
No additional preparation was required for the stack wagon.
[1]Use of wheelrake for windrowing corn residue.
[2]Flail shredder used to windrow residue.
[3]Based on using straw chopper.
[4]Field plus 0.5 mi to roadside.
[5]Equivalent to energy consumption of flail shredder.

Table 2. Residue Harvesting Systems and Energy Requirements.

System 1

Components	Energy Required Btu/ton
Flail Windrower	96600
Baler, large round	117125
Hauling[1]	10830
Loading	44550
Transporting[2]	358960
Total	628065

System 2

Components	Energy Required Btu/ton
Flail Windrower	96600
Baler, large rectangular	117125
Hauling	10830
Loading	44550
Transporting	213390
Total	482495

System 3

Components	Energy Required Btu/ton
Flail Windrower	96600
Baler, rectangular	65920
Stacking	124500
Loading	44550
Transporting	246500
Total	512150

Table 2 (continued)

System 4

Flail Windrower	96600
Forage harvester	180850
Hauling	10830
Module building	33000
Loading	22275
Transporting	260100
Total	592825

[1]Assumes tractor moves two bales at a time
[2]Assumes a payload of 6.5 tons (13 bales)

APPENDIX II

Corn Yield 1986-1990

County	1986	1987	1988	1989	1990	Ave.
Dawson	131	163	158	151	153	151
Buffalo	139	153	146	140	144	144
Hall	137	154	149	146	145	146
Phelps	143	160	167	153	165	152
Kearney	145	154	151	151	153	151
Adams	138	152	146	145	154	147
Harlan	133	147	135	142	151	141
Franklin	140	148	141	146	146	144
Webster	123	145	137	147	140	138
Clay	153	153	145	148	151	150
Sherman	117	118	129	126	122	123
Howard	127	137	127	134	130	131
Furnas	113	122	105	122	108	114
Gosper	136	154	156	141	147	147
Custer	128	138	135	118	125	129
Nance	121	110	109	114	118	115
Merrick	140	140	141	139	138	140
Hamilton	153	157	150	160	155	155
York	130	157	148	150	161	149
Filmore	146	151	150	154	139	148
Nuckolls	148	149	146	157	133	147
Seward	138	140	132	139	152	140
Thayer	154	147	143	159	139	148
Polk	121	147	133	130	142	135
Butler	124	125	119	119	125	122
Ave. Yield	135	145	140	141	141	140
Range	113-154	110-163	105-168	114-160	108-166	122-152

APPENDIX III

Corn Residue Produced by County
(000s tons)

County	Low (1:38:1)	High (1:1)	Best Estimate (1.27:1)
Dawson	604	833	656
Buffalo	552	762	600
Hall	578	797	628
Phelps	669	924	727
Kearney	536	740	583
Adams	459	634	499
Harlan	179	247	194
Franklin	204	282	222
Webster	101	139	109
Clay	438	605	476
Sherman	143	198	156
Howard	284	393	309
Furnas	139	192	151
Gosper	197	272	214
Custer	542	748	589
Nance	205	284	223
Merrick	446	616	485
Hamilton	708	977	769
York	605	835	657
Filmore	456	630	496
Nuckolls	111	153	120
Seward	256	353	278
Thayer	261	361	284
Polk	323	446	351
Butler	304	420	331
	9,300	12,835	10,106

APPENDIX IV

Mechanically Collectible Corn Residue by County (000s tons)

County	Low (1:38:1)	High (1:1)	Best Estimate (1.27:1)
Dawson	296	408	321
Buffalo	271	373	294
Hall	283	391	308
Phelps	326	453	356
Kearney	263	363	286
Adams	225	311	245
Harlan	88	121	95
Franklin	100	138	109
Webster	49	68	54
Clay	215	296	233
Sherman	70	97	76
Howard	139	192	151
Furnas	68	194	74
Gosper	96	133	105
Custer	265	366	288
Nance	101	139	109
Merrick	219	302	237
Hamilton	347	478	377
York	296	409	322
Filmore	224	309	243
Nuckolls	54	75	59
Seward	125	173	136
Thayer	128	177	139
Polk	158	219	172
Butler	149	206	162
	4,557	6,289	4,952

APPENDIX V

Corn Residue Less Soil Conservation Acres
(000s tons)

County	Collectible Residue	Soil Conversation Residue	Available Residue
Dawson	321	36	285
Buffalo	294	136	158
Hall	308	46	261
Phelps	356	29	327
Kearney	286	42	243
Adams	245	46	199
Harlan	95	13	82
Franklin	109	30	79
Webster	54	32	22
Clay	233	38	196
Sherman	76	63	13
Howard	151	93	58
Furnas	74	14	60
Gosper	105	8	97
Custer	288	66	222
Nance	109	60	49
Merrick	237	11	226
Hamilton	377	42	335
York	322	47	275
Filmore	243	38	205
Nuckolls	59	18	41
Seward	136	39	97
Thayer	139	50	89
Polk	172	21	151
Butler	162	67	95
	4,952	1,086	3,866

APPENDIX VI

Approximate Average Annual Cost Model

1. Annual Cost = Fixed costs + Variable costs + Timeliness cost

2. Fixed Costs

C_f = Annual fixed costs =

$$\frac{P - P' AB^n}{n} = \left(\frac{P + P' AB^n}{2}\right) R_{int} + P\left(R_{ins} + R_{tax} + R_{shl}\right)$$

P = Purchase price
P' = List price
n = Economic life
R = Rate (%100)
int = interest
ins = insurance
tax = tax
shl = shelter
A = Remaining value factor, multiplier (ASAE)
B = Remaining value factor, exponential (ASAE)

3. Variable or Operating Costs

C_V = Annual variable costs =

$$C_R + \frac{U_{aa}}{C}\left(F + O + L + T + M_h\right) + U_{aa}M_a$$

C_R = Annual equipment repair cost =

$$\frac{P' \; RF1}{n}\left[\frac{nU_{aa}}{1000\;C}\right]^{RF2}$$

RF1= repair factor (ASAE)
RF2= repair factor (ASAE)
U_{aa} = Use, annual acres

C = Effective field capacity =

$$\frac{S\ W\ E}{8.25}$$

S = Speed
W = Width
E = Field efficiency

F = Fuel
O = Oil = 0.1 * F

Fuel use is estimated by using the energy requirement for a specific operation which includes traction and transmission efficiencies. Fuel consumption characteristics are taken from the University of Nebraska Tractor Test Reports. Consumption in gal/h at full load and half load are used from the varying load power take-off test to obtain a regression line to estimate fuel consumption.

L = Labor
T = Tractor rate =

$$\frac{C_F + \frac{P' \ RF1}{n}\left[\frac{nU_{ah}}{1000}\right]^{RF2}}{U_{ah}}$$

U_{ah} = Use, annual hours
M_h = Miscellaneous, hours basis
M_a = Miscellaneous, area basis

4. Timeliness Cost

C_2 = Timeliness costs =

$$\frac{U_{aa}}{C}\left(\frac{KYVA}{XUh}\right)$$

K = Loss/day timeliness factor (decimal)
Y = Potential yield
V = Crop value
A = Annual use (U_{aa})
X = Average loss factor
U = Time utilization factor (decimal)
h = Hours field time per day