CORN STOVER COLLECTION PROJECT

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ABSTRACT

Corn stover is the largest quantity of biomass residue in the US, 200 million MKg (220 million tons) dry weight, with 30% to 60% available – 73 to 146 million MKg (80 to 120 million tons). The stover has the potential of supplying 23 to 53 billion liters (6 to 14 billion gallons) of fuel ethanol to the US transportation market, up to 10 % of total gasoline needs.

A custom-harvesting contractor has launched an innovative corn stover collection operation as a source for value-added products on a scale that has not been done before. Centered in Harlan, Iowa, it can be viewed as a pilot for developing the infrastructure for agricultural residue and other crop collection for biomass processing to ethanol.

- More than 50,000 tons were collected from 12,000 ha (30,000 acres) in the '97-'98 crop year at a cost of $34.76 to $39.30/dry MKg, depending on the amount of residue removed. Farmers received $21.50 to $94.27/ha, depending on the amount removed and the distance from the collection center. The remainder was paid to custom harvesters.

- The operation is judged successful, with a waiting list of more than 4,000 ha (10,000 acres). Expansion to 40,000 ha (100,000 acres) is planned for the '98-'99 crop year.

Improvement in productivity is expected to reduce costs to less than $33/dry MKg, the equivalent of $0.10/liter of ethanol. In addition, a preliminary assessment indicates co-products can further lower corn stover cost to $25/ dry MKg delivered. Expanding the operation to 200,000 ha (500,000 acres) to collect 1 million dry MKg of stover, then classifying the cobs from the stover as a higher valued product – more than $50/MKg – shows the area can readily supply a 190 million liter (50 million gallon) ethanol facility.

Keywords: Corn stover, collection cost, baling, economics, ethanol production

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INTRODUCTION

Until the '96-'97 crop year there was little experience collecting corn stover on a large scale. The large stalk makes it different from baling other stover. Presently, a small amount of stover is used for animal bedding. Its fiber content has some looking at its paper-making potential, but economics remain a hurdle. The great majority is left in fields to decompose.

Agricultural residues such as corn stover, soybean stubble and straw represent a huge, available and sustainable source of fuel. Their composition is about 70% cellulose and hemicellulose and 15-20% lignin. Cellulose and hemicellulose can be converted to ethanol and lignin burned as a boiler fuel for steam/electricity generation. Developing ways to quickly collect, handle and store biomass economically is required for biomass to ethanol commercialization, along with improved process technology.

The theoretical amount of ethanol per dry MKg of Ag residue is 500 liters (130 gallons/ton). Mature conversion technology yield is estimated to be near 80%, 415 liters, 108 gallons/ton (Lynd, 1996). For initial processes, an overall 60% yield is generally used, resulting in 300 liters (80 gallons/ton). The energy content in the lignin can offset the ethanol processing energy requirements.

CORN STOVER AVAILABILITY

<u>Amount of Residue:</u> Corn stover is by far the largest single available biomass residue. It represents more than 70% of the total, including municipal solid waste (Brower, 1993). Since it is not collected, it is estimated -- the most common ratio used is 1:1 or 1 MKg of above ground residue for every MKg of corn harvested (Larson, 1978; Gupta, 1979). Using this factor, and 16% moisture, corn stover for the past two crop years is given in Table 1.

Table 1: Corn Stover Estimate

Crop Year	1996/1997	1997/1998
Corn Production, MKg (USDA)	236	238
Corn Stover, million dry MKg /tons	198/218	200/220

<u>Sustainable Collection:</u> The sustainable amount that can be removed depends on soil, topography, crops, crop rotation, tillage practice, and environmental constraints. The USDA has published detailed guidelines for residue management. Percent residue cover of the soil surface is a more useful parameter than weight. Depending on the conditions, residue coverage of 20% to 65% is advised (Lindwall, 1994).

No-till fields have the least requirement for residue. One estimate places the collectible fraction of all Ag stover to be 58% (Wyman, 1990). Estimating 60% as corn stover's upper collection limit appears conservative due to its broad leaves and high quantity per acre. Present equipment limits corn stover collection to about 70%. Higher amounts may contain too much soil with the stover. Too much residue also causes problems, reducing the yield of the next crop (Smith, 1986).

To prevent wind erosion, a 10cm anchored stubble works for no-till. For water erosion, slope, slope length and ground coverage is important. The surface covered is important to absorb the kinetic energy of raindrops. For corn stover, leaving a cover of 1.6 tons/ha (0.7 tons/acre) on a silt loam soil having a 10% slope effects a 92% erosion reduction from a moldboard plow (Dickey, 1986).

For carbon sequestration, unless no-till is practiced, the amount of residue left has little effect. The carbon is lost as CO_2 when plowed: residue or no residue. Tillage causes rapid oxidation that can consume carbon faster than it is sequestered. . . and tillage appears to be the major reason soil organic matter continues to be depleted (Reicosky, 1995, 1997). A study recently completed shows no difference in soil organic matter after 30 years of silage removal compared to corn with the grain removed but all the stover tilled under (Reicosky, 1998).

HARLAN, IOWA CORN STOVER PROJECT

An industrial processor found it could lower cost using corn stover feedstock. Working with Iron Horse Custom Farming, Western Iowa Development Association and the Nishnabotna Valley Rural Electric Cooperative, a corn stover collection facility was constructed in Harlan, Iowa in 1996. Processing includes sampling, weighing, storing, milling and densification with related material handling for transfer to the industrial process.

<u>First Year, '96-'97 . . . A Learning Experience:</u> Meetings with local producers were held, and many showed interest in collecting stover for added income, and as a way to get rid of it without having to plow. In spite of these expressed intentions, available resources were consumed just harvesting corn. No time or equipment was available for the corn stover, 10% the corn value. Custom operators would be required for collection.

<u>Second Year, '97-'98 . . . Success:</u> Meetings were again held to enlist growers, and 440 contracts for about 20,000 ha of their corn fields resulted. Thirty plus custom harvesters were contracted to perform the baling. Corn stover collection on this scale had never been attempted before.

Start-up problems were mostly baler related: working to achieve a dense bale, with a minimum 550 kg (1,200 lbs) dry weight. These difficulties were worked out and several weeks of productive baling occurred prior to the first blizzard on October 27. Afterward, the field conditions for baling never recovered. About 12,000 ha (30,000 acres) were actually collected due to the wet, unusually warm winter.

Collection Process: The collection process takes two operations: 1) baling and 2) bale collection and delivery to the processor. The cost is $34.76/dry MKg delivered. Previous models for the collection process included up to eight separately staffed operations: raking, baling, field loading with a fork truck, field to area storage, unloading and area storage, load for highway transport, hauling and unloading at the plant. Cost estimates ranged from $31 to $45/dry MKg (Buchele, 1976; Cundiff, 1977; Richey, 1980; Sayler, 1993; Jose, 1996). Additional studies of agricultural stover harvest and collection are reviewed in detail by Lindley and Backer (1994).

The separate raking operation is replaced by turning off the spreader on the combine, leaving a windrow. This results in 3.4 - 4.5 dry MKg/ha (1.5 - 2.0 tons/acre) collected. Adding a rake in front of the baler can increase the amount to 5.6 to 7.9 dry MKg /ha or more (2.5-3.5 tons/acre). Area production of corn and above ground stover ranges from 18 to 22 MKg/ha dry weight (150 to 200 bu corn/acre, 4 to 5 tons/acre dry stover).

Both round and square balers were used. Round bales were wrapped with three layers of plastic net to insure they did not break apart when collected and handled for processing. The multi-layers also improved water shedding, reducing the need for storage buildings.

High bale density is desired to minimize hauling costs, and for round bales the wrapping cost, since bale wrap cost is a constant. The cost impact for both is shown in Table 2 and Table 3.

Table 2:Bale Density Related to Hauling Revenue

	6.95/7.65	7.73/8.50	8.50/9.35	9.27/10.2	10.0/11.0	10.8/11.9	Hauling Rate
Bale Weight, dry kg/lbs	410/900	450/1,000	500/1,100	550/1,200	590/1,300	640/1,400	$/MKg(ton)
0-25 km (0-15 miles)	$ 47	$ 52	$ 57	$ 62	$ 67	$ 73	6.71(6.10)
26-49 km (16-30 miles)	$ 67	$ 75	$ 82	$ 89	$ 97	$ 104	9.65(8.77)
Payment Per Loaded-Trip*	$ 88	$ 97	$ 107	$ 117	$ 126	$ 136	12.58(11.44)
Trailer Wgt, Dry MKg/Tons							

*Normal Load for Inland Trailer is 17 round bales per load, 6+6+5 Bales.

Table 3: Round Bale Density Related to Plastic Net Three-Wrap Cost

Bale Weight, dry kg/ Lbs	410/900	450/1,000	500/1,100	550/1,200	590/1,300	640/1,400
Wrap Cost, $/Dry MKg	$4.54	$4.09	$3.72	$3.42	$3.15	$2.93
Wrap Cost, Per Bale	$1.85	$1.85	$1.85	$1.85	$1.85	$1.85

A target of 550 kg (1,200 lbs) dry was set for both large round bales (5' wide, 70" dia.) and big (4'x4'x8') square bales. Most John Deere round balers achieved this density by using a shredder attachment to break up the large corn stalks. It is supplied by Heartland Manufacturing. The target dry weight for intermediate square bales was 300 kg (650 lbs). A shredder attachment is not required for the Hesston square balers.

Collection and hauling is done with one person and in one operation using "load and go" trailers, Figures 1, 2. The tractor cab contains a control system for moving the loading arm for the trailer. It is capable of picking bales up in any orientation, rotating them to the correct position and then loading them on the trailer. One trailer manufacturer is Inland Steel & Forgings Ltd. Another is Golden View Fabricating Ltd.

Figure 1. Staging Demonstration for Square Bales with JCB Tractor.

Figure 2. Staging Demonstration for Round Bales.

The bales are picked up where they are left by the baler in the field while traveling 10 to 12 km/h (6-7mph). A loading cycle -- 17 round bales, about 9.5 MKg (21,000 lbs) dry -- averages less than 20 minutes. Some haulers employ high-speed tractors, JCB's, Figure 1. Others include Unimogs, supplied by Mercedes Benz. These tractors can comfortably traverse fields, cross ditches collecting bales and then safely travel at highway speeds up to 100 km/h (62 mph) enroute to the collection center. At the collection center the load is weighed, sampled for moisture, and unloaded. In less than 10 minutes the operator is on the way to the next field.

Figure 3. Loaded Trailer, Ready for the Highway.

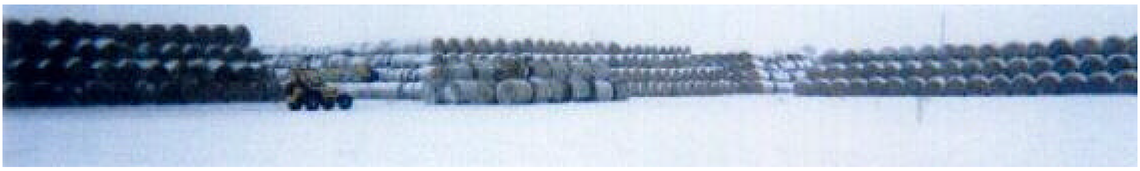

Figure 4. Outside Storage of Corn Stover.

All bales are stored in the open, Figure 4. High moisture round bales and uncovered square bales are processed first. Normal moisture round bales are processed later, largely protected from the weather by the plastic wrap.

<u>Corn Stover Pricing:</u> The delivered price for the stover was $34.76/dry MKg if about 8 MKg/ha (3 tons/acre) were collected. If only 4 MKg/ha (1.5 tons/acre) were harvested, the price increased to $39.30/dry MKg. Most producers chose for higher collection, Case 2. Producers with sloped land mostly chose Case 1.

The two prices were based on perceived quality differences in bale composition, which was not demonstrated. The two tier pricing has been discontinued this year.

The baler received $16.06/dry MKg, regardless of the density. Table 4 summarizes corn stover pricing used for the '97-'98 crop year:

Table 4: '97-'98 Corn Stover Pricing Summary

Payments, Dollars per Dry MKg (ton)				
Radius, km/Miles	**0-25/0-15**	**26-49/16-30**	**50-80/31-50**	**81-164/51-100**
Producers Revenue				
1) 4 dry MKg per ha	$16.50(15.00)	$13.56(12.33)	$10.63 (9.66)	$ 7.70 (7.00)
2) >5.5 dry MKg per ha	$12.00(10.90)	$ 9.05 (8.23)	$6.12 (5.56)	$ 3.19 (2.90)
Baler's Revenue	$16.06(14.60)	$16.06(14.60)	$16.06(14.60)	$16.06(14.60)
Hauler's Revenue	$ 6.71(6.10)	$ 9.65 (8.77)	$12.58 (11.44)	$15.51 (14.10)
Total, Case 1	$39.30(35.70)	$39.30(35.70)	$39.30(35.70)	$39.30(35.70)
Total, Case 2	$34.76(31.60)	$34.76(31.60)	$34.76(31.60)	$34.76(31.60)

The producer had the option to perform the baling, trucking or both baling and trucking at the same price. The custom operators use of specialized equipment made it difficult for the farmer to be competitive. Few producers participated, continuing to remain focused on harvesting the corn crop, their largest revenue source.

LESSONS

The collection is widely viewed as a success. There are 10,000 acres on a waiting list for the next crop year. Similar operations for corn stover collection are now being planned by organizations in Illinois, Nebraska and Wisconsin. There remains much room for improvement and several issues continue to be debated including harvest radius, windrow formation, productivity gain methods and the harvest window (field days for baler operation).

<u>Large Harvest Area Desirable:</u> The radius – mostly within 80 km (50 miles) -- was drawn to provide a diverse area for harvest. When conditions were poor in one section, operations were shifted to another. This strategy proved itself this past year when weather conditions were most unfavorable. While more travel was incurred, it was offset by less idle time.

<u>Windrow Formation Issue:</u> All the producers were contractually required to turn off the spreader on the combine to form a windrow. If the windrow is not removed, it interferes with next season's planting. A penalty of $15 to $37/ha, depending on contractual completion date, compensates the producer for the extra effort in dealing with its removal.

Due to poor field conditions caused by the weather about 8,000 ha (19,768 acres) were not collected, subject to penalty payment. Whether to use the spreader in the coming year remains an option. If the stover is spread, rakes mounted on the tractor or in front of the baler are needed.

<u>Improve Baler Productivity</u>: High bale density is essential to achieve desired cost and productivity. A $0.55 per MKg premium will be paid to the baler in the coming year for those who meet the target to reflect its importance in controlling wrap and transport cost. Best practices for corn stover baling operation will be shared during "baler school" to be held before the harvest. It will focus on attaining the bale density targets.

<u>Shorten Harvest Window</u>: To reduce the risk of not completing the harvest due to weather related conditions, the number of contract balers will be increased to shorten baling time in the field. Most will be offered 400 ha (1,000 acres)/baler, representing about 30 operating days. This is just half of the 800 ha (2,000 acres) offered to the balers last year, requiring an unattained 60 days in the field.

FUTURE SCENARIOS

The project centered around Harlan, Iowa can be viewed as a pilot for other agricultural residues and energy crop collection of biomass processing to ethanol and electricity. The experience is yielding ideas for large volumes of more diverse products at lower cost, including the co-product separation of corn cobs. The potential of selling the higher value cobs may result in a Harlan Project Extension. Additional planned actions will also improve productivity, equipment utilization and collection economics by more than 20% overall.

Harlan Project Extension: A Preliminary Assessment for the Harlan, Iowa area shows the delivered cost of the corn stover may be reduced to $25/dry MKg, about 8¢/liter ethanol (30¢/gallon) by separating the corn cobs from the baled stover. The cob co-product has a value of about $50/MKg 'as is.' A local processor has a need for 200,000 MKg of cobs, possibly increasing to 300,000 MKg per crop year.

The baled corn stover contains 20% cobs. With a basis of one million MKg of corn stover collected as a minimum, 800,000 MKg of corn stover residue remains after the cob separation. This is equivalent to more than a 230 million liter (60 million gallon) ethanol plant. The local economic development organizations are examining possibilities for matching up this stover supply with potential biomass processors.

Producers in outlying areas are favorably inclined to establish collection/processing centers nearby, reducing the hauling cost. It provides an outlet for corn stover in lieu of plowing it under or otherwise distributing it so the next crop is not impeded with excessive stover (Smith, 1986.) Discussion with these local producers and contract harvestors indicates another 6 to 10 collection centers can be readily supported, each potentially collecting 100,000 to 200,000 MKg within a 20 to 35 km 12 to 22 mile) radius.

The plan is to form a farmer cooperative that would organize and manage the corn stover and other crop collection and sale much like grain elevators. It coordinates collection and storage, and carries the cost of the material until ordered by the processor. It arranges delivery, invoices, receives payment from the processor and then distributes the proceeds to the producer, hauler and others as contracted.

At each collection center, the corn cobs are readily classified from the corn stover. The cobs can be shipped in loose form for further processing, generating annual revenues of $10-15 million. The remaining stover can be re-baled, using a high-speed industrial baler. The high density bales would be stable, and of the best size and shape to maximize payload for further transportation. They also represent a 'bankable' asset for cash management.

Cost on the plant dock is expected to be about $25/dry MKg, about 8?/liter or 30?/gallon ethanol.

Future Extensions include use of a more diversified feedstock, activities which reduce transportation cost -- including revising laws and regulations, further collection improvements, inventory shrinkage prevention methods and co-product collection.

Diversified feedstock for a biomass processing plant is available in addition to corn stover. Much of the same collection equipment is utilized. The result is a decline in fixed costs, lowering collection costs without shrinking margins. Soybean stubble is collected now for animal feed, yielding between 2.2 to 3.5 MKg/ha (1.0 to 1.5 tons/acre) dry weight. Switchgrass becomes attractive with lower collection costs. Alfalfa and other grasses are possibilities, especially if the planned protein extraction plants for alfalfa proceed. The certainty of a diversified crop base reduces the custom operators and processor's dependency on a few crops, enhancing the economic possibility for capital investment.

Transportation cost reductions are occurring now with wider use of JCB/Unimogs type tractors that shorten travel time between field and collection centers. More collection centers with a smaller collection radius will emerge. The increased number coupled with central scheduling of collection equipment will allow high utilization of these resources, adjusting to changing field and weather collections, insuring timely and efficient harvest.

Legislation and regulatory changes to better standardize requirements and facilitate safe, efficient and easy state to state and Canada and US highway equipment operation can also reduce cost. Iowa has already made changes that permit custom operators to operate under the same conditions as the producer when transporting crops from field to markets. Without this change, additional license and insurance fees would have increased cost for the operator.

Further cost improvements in the baling, wrapping and collection equipment and process is expected to increase payload and lower cost by 30% or more. A variety of equipment development plans are underway, such as adapting cotton harvest compaction trailers, making improvements to balers to operate at greater compaction pressure and re-designing the dated 'stacker' for high volume, custom operation.

Inventory shrinkage prevention continues to be investigated. Processing high moisture round bales and uncovered square bales during colder weather can minimize inventory shrinkage. Wrapped round bales with moisture levels less than 20% remain stable, and may be processed later in the season at a rate to match processing requirements. A more detailed study to measure parameters, further relating cause and effect is planned for this crop year.

Co-product collection via bales offers considerable flexibility and provides an attractive alternative to collection systems in place for corn, soybeans, wheat and other cash crops. The co-products may be milli- or micro- quantity components present in the plant or an expressed material in a transgenic plant.

Cash crop systems are designed to move large volumes of homogenous material efficiently. They are not readily adapted to segregating materials or handling "special" situations. Cross-contamination would be an ever-present concern. If contamination does occur, the mistake is usually irreversible, as mechanical separation of physically identical grain is not possible.

Baling allows easy segregation. Bar-coding bales provides low cost, accurate inventory control. Co-products can be separated at the collection center. The processed biomass may be re-baled using an industrial baler and later transported. The valuable co-product can be collected for further processing on site or elsewhere.

In summary, the Harlan Project offers the opportunity to speed the development of bioenergy production in the corn growing Midwest region. It serves as a model to further the infrastructure development for biomass collection to supply a sustainable energy future.

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