October 2000 • NREL/SR-580-28886

Subcontractor Report

Biomass Commercialization Prospects in the Next 2–5 Years

BIOMASS COLLOQUIES 2000

J.R. Hettenhaus
cea, Inc.
Charlotte, North Carolina

Technical Monitors and Contributing Authors:
R. Wooley and A. Wiselogel
National Renewable Energy Laboratory
Golden, Colorado

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1617 Cole Boulevard
Golden, Colorado 80401-3393

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EXECUTIVE SUMMARY

A series of four colloquies held in the first quarter of 2000 examined the expected development of biomass commercialization in the next 2 to 5 years. Each colloquy included seven to ten representatives from key industries that can contribute to biomass commercialization and who are in positions to influence the future direction. They represented:

- Corn Growers
- Biomass Suppliers
- Plant Science Companies
- Process Engineering Companies
- Chemical Processors
- Agri-pulp Suppliers
- Current Ethanol Producers
- Agricultural Machinery Manufacturers
- Enzyme Suppliers

Others attending included representatives from the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory, the U.S. Department of Energy’s Office of Fuels Development, the U.S. Department of Agriculture, environmental groups, grower organizations, and members of the financial and economic development community.

The informal discussions resulted in improved awareness of the current state, future possibilities, and actions that can accelerate commercialization. Biomass commercialization on a large scale has four common issues:

1. Feedstock availability from growers
2. Large-scale collection and storage
3. An economic process
4. Market demand for the products

The colloquy participants indicated the first two issues above — feedstock availability and collection and storage are most likely to occur when an economic process is demonstrated and large-scale commercial production is imminent.

Lack of commercial-scale demonstration of the process was seen as a major impediment due to high cost, associated risk, and uncertain future for government policies that can impact the market. Process economics that have been validated on the required scale, about 50 tons (t) per day of feedstock, coupled with an attractive market outlook are key for the biomass industry to emerge.

Grower Benefits

A limited number of producers are recognizing the potential benefits from collection and sale of agricultural residues, especially corn stover. Corn stover is the surface material remaining after the grain is removed. Large-scale corn stover harvesting experience shows stover sales can add $40 or more per acre when using custom operators for baling. Collection of the excess stover improves residue management practices and reduces tillage, erosion, and the use of chemicals. Collection also offers significant carbon credits through carbon sequestration and reduced greenhouse gas (GHG) emissions by using biomass to offset fossil fuels.

Wider understanding among the producers of the potential benefits of stover collection is expected to occur when the first stover processing plants are built. An early grasp of its value by producers can increase support for accelerating efforts to achieve commercialization.

The Other Half of the Crop

Plant sciences are expected to increase the biomass productivity as a market develops for its use. It is probable that the cellulose content will be increased and the lignin composition reduced to improve sugar yield from the biomass without affecting structural integrity. It is also likely that enhanced plant properties will make processing to fermentation sugars and processing for agri-pulp fibers easier. Expression of cellulase enzymes in the structural components of plants are viewed as more difficult, and are not expected within the next 5 years.

Collection and Storage

To ensure collection of the large quantities needed for biomass processing, custom operators using existing balers are expected to be organized by "biomass suppliers." Producers are fully committed to successfully completing the traditional cash crop. They do not have the resources to collect the huge quantities of feedstock required in the allotted time.

Biomass suppliers have demonstrated the collection of 50,000 acres of corn stover for a single collection site. Their success has largely alleviated large-scale collection and storage concerns. At least six entities in the corn belt states are organized to collect, store, and supply 1 million tons of agricultural residues, mostly corn stover, at a cost between $25 to $50 per dry ton--delivered within a 50-mile radius. Existing balers will play a major role in the near-term collection of agriculture residues. Development of new collection equipment is expected when customers for it emerge.

Process Validation

Many consider commercialization too risky for a process that is demonstrated with equipment that requires a 100-fold increase in vessel size or a 1,000-fold increase in process throughput. Process validation of new technology on a near commercial-scale appears key for project financing unless loans are guaranteed.

“When will an economic biomass process be validated?” remains an open question. Most expect that improvements in enzyme hydrolysis and process yield will lower capital requirements and result in a successful demonstration within the next 2 to 5 years—and the first successful process quickly adapted to similar applications. The following efforts are being closely watched.

- Iogen has a $25 million CN demonstration plant that employs both cellulase enzyme hydrolysis and hemicellulose fermentation. The single process train uses 40 to 50 tons per day of wheat straw, corn stover or switchgrass and "commercial scale" vessels. Once the process is validated, design and construction of a 1,500- to 2,000-ton-per-day plant is planned, with its start-up expected in early 2003. Cost is expected to approach $200 million.

- BC International plans to have the Jennings, LA plant in operation when financing is arranged. This plant will use a proprietary fermentation strain for ethanol production. Its capacity is rated at 20 million gallons per year, processing about 1,000 tons per day of bagasse and rice hulls that do not have a collection cost. They will initially use dilute acid for cellulose and hemicellulose hydrolysis. Cellulose enzymatic hydrolysis is expected to be added as the process becomes available to BCI.

- Acid hydrolysis is viewed by most to be mature technology relative to biochemical processes. The concentrated acid process is seen as best suited for municipal solid waste with high tipping fees—not for corn stover or other agricultural residues that have a cost associated with their collection. As a result, Masada and Arkenol projects were of lesser interest to the colloquy attendees.

- Existing wet millers are also expected to have economic conversion technology for corn fiber to fermentation sugars during the next 5 years, thus providing an alternative for gluten feed sales in the European Union market.

- Agri-pulp processes that produce a pulp similar to hardwood pulp for paper products and that use the hemicellulosic sugars for fermentation products, avoiding the cost of recovery boilers may also emerge within the 5-year period.

Dry Mill Potential for Co-Production of Hemicellulose Sugars

Existing dry mill ethanol plants may have a route to process about 50 tons per day of corn stover on a "'pay as it goes" process that can increase production of ethanol while evaluating pretreatment, enzyme hydrolysis, and pentose sugar fermentation.

Removing the germ via a "quick steeping" process or some of the hemicellulose from the Distillers Dry Grains-Solubles (DDGS) via a hydrolysis step, corn stover can be added to maintain 26% protein. The corn stover is first hydrolyzed, and the sugar stream can be fermented separately, increasing ethanol production 6%-12%.

By adding corn stover to maintain DDGS protein levels, 40 to 60 tons of stover--enough to validate the process technology--can be pretreated per day. For a 12-million-bushel plant, another 2 to 4 million gallons of ethanol can be produced from the combined sugars of DDGS and corn stover.

The capital costs for the above scenario are expected to be relatively low, especially if distillation is not the bottleneck. In addition, the processors gain experience with corn stover harvest, storage, its processing, and fermentation of hemicellulosic sugars. The DDG/corn stover opportunity requires more study, but potentially provides a low-risk route to advance the biomass conversion technology.

Co-Processing of Agri-Pulp and Fermentation sugars

A 1,000-ton-per-day biomass plant for ethanol generates $30 million in revenue based on NREL yields and $1.00 per gallon (gal) of ethanol. Pulping the cellulose raises the plant revenue to $70 million or more. The paper quality from corn fiber has passed initial tests, and at least four independent efforts are underway to move to a demonstration plant scale to validate the process and supply potential customers with larger quantities for evaluation.

Market Potential

The existing market for corn stover is extremely limited—less than 5% of the 160 million tons available. Cereal straw supply also greatly exceeds demand. Development of new markets is dependent on demonstration of favorable process economics and product need. Two large markets are seen emerging: fermentation sugars and fibers.

- Fermentation sugars costing $3-$5/hundred weight (cwt) are attractive for production of fuel ethanol, chemicals, and plastics. This potential feedstock market is in excess of 100 million tons.

- Potential fiber demand for agri-pulp and particleboard applications is less, about 30 million tons, but offers two to four times the product value.

Environmental Benefits

Removing corn stover reduces the need for many producers to plow, thus reducing erosion and chemical usage. Processing the stover into products that replace fossil fuels and improve tillage practices has a significant impact on groundwater quality from reduced chemical usage. Field runoff water quality is improved, resulting in less eutrophication. Harvesting 30% of the total corn stover and processing it to offset fossil fuels reduces GHGs by nearly 500 million metric tons of carbon equivalents.

Government Policy

The need for continued funding of process research and development, assisting the construction of demonstration plants to validate process technology, and establishing a policy for costing external factors such as GHG mitigation, were all cited. Continuing the present subsidy for bioethanol until further production cost reductions are achieved is also important for accelerating commercialization. Consistent policies among local, state, and federal agencies are also desired to increase harvesting equipment utilization across borders and permit collection of excess stover.

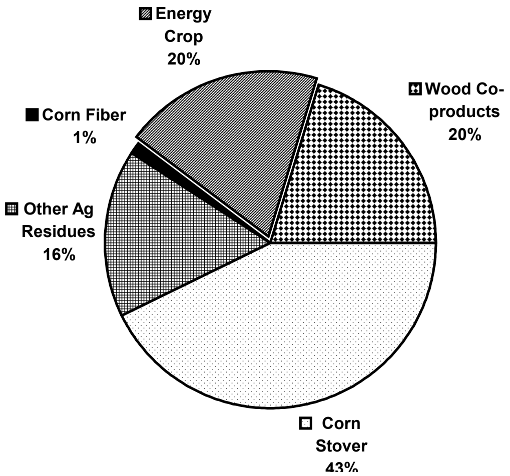
In the past, government loan guarantees were most successful in starting the existing corn-to-ethanol industry. Some believe this is the best route for starting the lignocellulosic biomass industry to ensure project financing. Others suggest an industry consortium may be effective with strong support from DOE/NREL and others to successfully complete the demonstration stage.

INTRODUCTION

Likely scenarios for biomass commercialization over the next 2 to 5 years were discussed in four colloquies held in February and March 2000. The sessions focused on corn stover due to its quantity and ready availability (Glassner et. al. 1998) (Table 1). Corn stover is the surface material remaining after the grain is removed.

Table 1.
Biomass Available at $50/Dry Ton or Less
(Millions of Dry Tons)

Corn Stover	Other Ag Residues: Straw, SB Stubble	Corn Fiber	Energy Crops	Wood Co-Products
153	58	4	70	72



Each colloquy included seven to ten participants in a position to influence the future development of the industry. They represented disciplines key for advancing commercialization. The following industry segments were included:

- Producers
- Biomass Suppliers
- Agricultural Machinery Manufacturers
- Enzyme Suppliers
- Plant Science Companies
- Potential Processors
- Ethanol
- Chemicals & Plastics
- Agri-Pulp
- Process Engineering Firms

Participants generally had a broad knowledge of the issues, with in-depth expertise in one or more of the key areas. This enabled them to contribute in two ways:

- Provide facts and discuss the future possibilities for their discipline
- Possess adequate related experience and judgment to evaluate and constructively question the possibilities suggested by others.

In addition, the audience had representatives from the U.S. Department of Energy's (DOE's) Office of Fuels Development (OFD), the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), the U.S. Department of Agriculture (USDA) and other organizations interested in the outcome--including the Farm Bureau, Institute for Local Self Reliance, state corn grower associations and economic development organizations. Their observation of the process and occasional participation on particular points of interest was beneficial. Benefit was obtained from the varied perspectives offered by these individuals with diverse interests, still allowing the participants to dominate the discussion. A listing of attendees is in Appendix A.

Each colloquy began with the facilitator stating the purpose of the colloquy. A few points for each segment were listed on a flip chart as an introduction for that segment. An open, informal discussion ensued, beginning with the producer's perspective and working through the supply chain.

The facilitator guided discussions to ensure each participant shared in the development and others in the audience helped clarify and develop topics. There were no presentations with the exception that the two following cases were developed with the audience by the facilitator:

- Pretreating Distillers Dry Grains (DDG) to remove some C_5 sugars and adding pretreated corn stover to maintain 26% protein—fermenting the C_5 sugars to ethanol in existing Dry Mill plants
- Co-processing corn stover to agri-pulp and fermentation sugars.

Comments were captured on flip tablet sheets and posted on the meeting room walls. They included issues associated with each segment, along with potential obstacles, drivers, and support needs.

Each colloquy was adapted to fit the participants and complement knowledge gained in previous sessions. Competitors were not included in the same session, encouraging open discussion.

At the conclusion, the participants and others in the audience stated they gained much from the multi-disciplinary discussion. The exchange of views with peers, which complemented their expertise, provided all with broader, improved perspective of the possibilities. The results from the four colloquies summarized in this report will be distributed to the participants and others in the audience.

The findings will be used to help set research and development priorities to accelerate commercialization of lignocellulosic feedstocks to fuel, chemicals, and other industrial products by DOE, especially OFD, NREL, and ORNL.

INDUSTRY SEGMENTS

1.0 PRODUCERS

Key Issues: Corn & Corn Stover Production

- **Residue management** has become more difficult as corn yields have risen. Most growers have increased tillage to remove the material from the surface. This increases soil erosion and lessens carbon sequestration in the soil. If stover were removed, most producers indicated they could reduce tillage.

- **A fair price** for the stover varies, dependent on the local situation, as does the amount of stover that may be removed. A producer in river bottomland that applies manure may offer it for $10 or less per acre to a biomass supplier. Another producer requiring phosphorus (P) and potassium (K) nutrients from the stover may want more than $20 per acre.

- **Carbon credits** are expected to become valuable as GHG mitigation efforts increase. This can add significant benefits to stover removal.

- **Past practice** — Plowing under the stover--is difficult to overcome without a strong reason to change. At present, the alternative for many farmers in the northern part of the corn belt is ridge till, which few have embraced.

- **The present stover market** is nonexistent, with less than 5% of the stover harvested for bedding and forage crops.

- **A business model** that makes feedstock collection and processing a win-win situation for the producer and the processor is desired, enabling both to benefit from the outcome. For collection and storage of the feedstock, biomass suppliers are considered more effective and efficient than either the producer or the processor performing collection, transportation, and storage.

1.1 Residue Management

As corn yields have increased, the quantity of corn stover has also increased. The ratio between corn stover and corn is about 1:1, i.e. 1 ton of corn stover is produced per ton of corn.

In the northern part of the corn belt the surface residue must be removed so the soil warms in the spring for the required growing season. In irrigated fields, it must often be removed to avoid interfering with water flow. *A yield of 160 bushels per acre (bu/ac) leaves 4.5 tons of stover per acre. In irrigated areas where 200 bu/ac is often exceeded, 6 to 7 tons of stover remain*[1]*.*

To manage the residue, most producers plow the stover under to remove it because it is slow to decompose (Annual Conservation Tillage Information Center Survey). Some producers practice ridge till or strip till, leaving a row with a clean surface to permit soil warming. Others are using alternative forms of “cleaning” so the soil surrounding the seed is exposed. Table 2 shows little no-till occurs in MN and WI due to the colder weather.

Table 2 % Corn Grown as No-Till

Year	1992	1993	1994	1995	1996	1997	1998	Avg
US	14	17	18	18	17	17	16	17
IL	18	20	19	18	15	NA	NA	18
IN	17	20	24	25	20	NA	NA	21
IA	12	15	19	17	14	NA	NA	15
MN	2	3	4	3	3	NA	NA	3
WI	6	9	10	11	11	NA	NA	9

Source: Annual CTIC National Conservation Tillage Survey

Surface residues help retain soil moisture. Where cold soil temperature is not a concern, this water-holding capacity can be beneficial. However, it increases the risk of alfatoxins in the corn. Surface material may also interfere with the planting of the next crop and make weed and pest control more difficult.

Normally corn is planted in 30- to 36-inch rows. Narrower rows--15 to 20 inches –are being tried to increase yield and provide a better canopy to offset higher moisture loss that occurs when there is no stover on the surface. The canopy can also moderate diurnal temperatures.

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[1] *Sections in italics have been inserted by the authors to add supplemental information.*

Some growers allow cattle to graze in the field after the corn is harvested. The cattle much prefer to eat the dropped corn kernels rather than the stalks. Removing the stover makes it easier for the cattle to find these kernels. Dropped corn is heavier than the stover and most is left behind when baling. If stover is not removed, about 1 ton of stover--mostly husks and leaves--is consumed with the kernels by the cattle, according to Iowa State University Extension studies. The rest is either trampled in the ground or wasted in other ways. *The kernels are estimated to average 4% of the residue in a normal harvest* (Strohbehn 1993).

Many producers agreed that removing the stover would allow them to reduce their tillage or go to a no-till method, depending on local factors such as soil type, slope, crop rotation, and soil nutrient requirements. They said it would reduce the amount of chemicals applied but probably not nitrogen (N) fertilizer. N fertilizer is generally applied based on expected yield and soil analysis.

Where the field is flat or has a slope of less than 6% and the soil structure is suitable, removal of some of the stover is believed to be beneficial. Some producers that are removing their stover said that one less pass with the disc appears to save more soil organic material (SOM) than leaving the stover. For their situation, fields that were harvested had better tilth the following year.

The collection of corn stover is not appropriate in all situations because of erosion concerns and corn stover’s moisture retention. Where stover is harvested, soil conservation guidelines are followed, leaving 30% or more of the surface covered after collection. On average, about 50% is estimated to be available for collection in southwest Iowa. In central Illinois, more than 60% is likely to be available from the relatively flat fields without erosion concern.

The amount of stover available is primarily based on an earlier study by the USDA Agricultural Research Service (ARS) that determined the amount of corn stover and other crop residues that could be removed in the corn belt without undue damage to the soil--meeting soil erosion *prevention requirements (Lindstrom et. al. 1981[2]). Crop acreage and yield data for 1972-1977 were compiled by counties for the Major Land Resources Areas (MLRAs) in the corn belt states. The average corn yield was 87 bu/acre. When current yields are applied, nearly 160 million tons of stover is estimated to be available today, based on the 1981 study methodology.*

The USDA is currently restudying the amount that needs to be retained for erosion control using revised models and new information. In addition, the long-term effect on the soil of stover harvesting with conservation tillage or of no-till appears to be an open question that the study is expected to answer.

Participants agreed additional study of stover harvesting impact is needed on soils that fit the local situations. The following related issues were raised in the discussion:

- What is the impact on soil erosion and carbon sequestration for various cases, including the following situations?

    1) Leaving 6 - 12 inches of anchored stubble in the field, removing the remainder (silage model) and no-tillage

    2) Removing the residue from the seed planting row via the variety of tillage practices: disc and chisel plow, strip till, ridge till, cleaning and planting 12-inch rows and other variations

    3) Corn-corn rotation, corn-corn-bean-bean rotation, corn-bean rotation, and other variations that include cover crops and forage crops in the rotation

- Will stover harvesting require more or less N fertilizer?

- What is the impact of removing the lignin contained in the stover? Lignin is more recalcitrant to breakdown than the cellulose and hemicellulose. Is it desirable to return lignin to the soil after it is extracted

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[2] W.E. Larson, co-author, participated in the Minneapolis Colloquy.

from the corn stover in the process? And if so, in what form is it most effective? Will the processing need to consider leaving lignin in the "proper" form to be recycled to the soil? What is its impact on the soil and on plant growth?

- What is the impact of harvesting stover and tillage practices on soil compaction? Some data shows no-till soil after 4-6 years is most resistant to compaction. Is this a factor to help bridge current producer compaction concerns resulting from the stover harvest?
- What is the stover removal impact on fertilizer requirements for micronutrients?
- What is the impact of removing soybean stubble and other crops in the rotation with corn? What is the impact of frequency of removal?

While the participants appeared to have a good grasp of the issues, they expressed concern that many farmers are not aware of the impact of tillage on sequestering carbon or questions related to removing the stover. Many believe the surface material contributes significantly to SOM. In contrast, studies by the National Soil Tilth Lab show that more than 80% of the stover remaining on the surface is lost as carbon dioxide and about 40% of the roots contribute to SOM (Cambardella and Gale 1999)[3].

Plowing the stover under can cause a deficit in SOM due to oxidation (Reicosky and Lindstrom 1993). A 30-year study of continuous corn showed no difference in the carbon sequestered in the top 6 inches of soil between the silage field, where all the surface material was removed, and the field where only the grain was removed and the remaining surface material was plowed under (Reicosky et. al. 1998)[4].

1.2 Fair Price—Value of Stover

The stover value is generally seen as a credit for the P and K nutrients removed, some reduction in tillage, and the price paid by the purchaser. The corn stover nutrient value for P and K is in the range of $3.20--$4.10

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[3] C. Cambardella participated in the Cedar Rapids Colloquy.

[4] D. Reicosky participated in the Minneapolis Colloquy

per dry ton (Hettenhaus et. al 2000). Analysis by independent labs shows P is about 0.1% and the K is 1%. In fields where manure has been applied on the basis of N requirements, P is already in excess, and possibly a quality concern for water run-off.

The value for N is more complex, depending on crop rotation and tillage practices. Microbial action is highest when the carbon/nitrogen (C/N) ratio is near 10. Due to the high C/N ratio of the stover, 30 to 70:1, additional N may be necessary to avoid denitrifying the next crop.

Depending on the crop rotation, some recommend 1% N fertilizer be added with the stover plowed under, 20 pounds (lbs) of N fertilizer per ton of buried stover. At $0.16/lb for N fertilizer, $3.20 is about the same value of the nutrients if they are removed.

Table 3 summarizes the estimated value to the producer for harvesting corn stover for various production levels:

Table 3 Corn Stover Value

Basis: 1 dry ton left/acre, Bu/acre.	130 Bu	170 Bu	200 Bu
1:1 ratio, 16% moisture, sell dry tons.	2 t/ac[a]	3 t/ac	3.8 t/ac
P & K Nutrients ($3.20/dry ton).	$(6.40)	$(9.60)	$(12.00)
Tillage, Cultivating	$10.00	$10.00	$10.00
Stover Sale ($40/ per dry ton).	$80.00	$120.00	$152.00
Total revenue increase/acre	$84	$120	$150

[a] tons per acre

At present, producers in the discussion are not making any allowance for the N fertilizer-stover relationship, continuing to follow previous experience based on yields.

Further study of the potential interdependence is needed. Harvesting 30% of the stover would reduce the need for up to 800,000 tons of N fertilizer. Others point out the system complexity and question the amount of fertilizer that may be reduced. The present USDA ARS study is expected to provide information that is more conclusive.

Removing the stover may reduce tillage costs. Avoiding intensive tillage has more savings—for example, one less disking reduces the cost by $10 or more per acre.

Some producers graze their cattle in the fields following harvest. The total benefits are estimated to be $12.50 per acre, $2.50 attributable to the crop enterprise and $10.00 to the livestock enterprise, based on 60 cows grazing 160 acres of crop residue for 120 days (Rasby et. al. 1998). Because more dropped corn would likely be consumed if it were not covered with 5 or more tons of other residue, this value is expected to increase.

Because most producers are fully occupied with harvesting the cash crop, custom operators are normally required and the baling cost, $15/dry ton, is deducted in Table 4. Table 4 does not include transportation from the field to the processor. It is highly dependent on distance and bale density. It is typically between $6 and $12 per dry ton and is discussed in a later section.

Table 4. Corn Stover Value Producer Revenue After Custom Baling Cost Deduction

Basis: 1 dry ton left/acre, Bu/acre	130 Bu	170 Bu	200 Bu
1:1 ratio, 16% moisture, sell dry tons. . .	2 t/ac	3 t/ac	3.8 t/ac
Revenue increase/acre	$84	$120	$150
Less Baling Cost, $15/dry ton	(30)	(45)	(57)
Producer Net /acre after baling	$56	$78	$93

1.3 Carbon Credits

Carbon credit trading is emerging as a major vehicle for mitigating GHG and thereby complying with the Kyoto Protocol. Corn stover processing can play a major role here. Using guidelines for carbon sequestration in soils with less tillage or no-tillage, associated N fertilizer reduction and the fossil fuel offset from processing biomass (Lal et. al. 1998), 30% of the corn stover can offset 100 million metric tons of carbon equivalents--up to 20% of U.S. emission reduction requirements of 500 million metric tons of carbon equivalents.

The market for carbon credits is expected to grow over the next 5 years and beyond. Using a value of $10 per ton of carbon, the potential benefit to the producer is an additional $18-$31 per acre, shown in Table 5. Carbon sequestration in the soil from corn is $3-$4 per acre. Removing the corn stover (leaving 1 dry ton per acre) and processing it to offset products from fossil fuels can add another $15-$27 to the value. No credit is taken for the N fertilizer reduction.

Table 5. Corn Stover Carbon Credit Potential

Basis: On bu/acre left, Bu/acre. . . . . 1:1 ratio, 16% moisture, sell dry tons. . . .	130 Bu[a] 2 t/ac[b]	170 Bu 3 t/ac	200 Bu 3.8 t/ac
Carbon Credit, $10/ton C			
Sequestration (with less tillage or no-till).	*$2.70*	*$3.30*	*$4.20*
Fossil Fuel offset	*$15.20*	*$21.00*	*$26.60*
Total Carbon Credit/acre	*$17.90*	*$24.30*	*$31.00*

[a] bushel

[b] tons per acre

1.4 Past Practice

There is much inertia to overcoming past practice and previous experience. Collecting stover for other uses is not a new idea. Heartland Fibers LLC has worked with producer groups from many parts of the corn belt to evaluate potential corn stover supply for an agri-pulp process. Their efforts over the past 10 years have educated many to the possibilities, but the commercial efforts were not successful. Others have looked at co-firing stover and using it for upscale horse bedding, also unsuccessfully.

Once an idea is rejected, it is difficult to reverse. Unless a significant benefit is associated with harvesting some of the stover, it is expected many producers will continue with business as usual. Depending on the incentives, grower participation is expected to increase with demonstrated success.

1.5 Corn Stover Market

Stover is the largest underutilized crop in the United States. Less than 5% of the stover currently has a market. Some experts place this market at less than 2%. The stover volume available for potential markets is huge when compared to everything except fermentation sugars and agri-pulp. The opportunity lost to the producers is $6 billion based on 60% available and a sales price of $40/dry ton.

Selling stover has the potential to reduce the need for continued farm aid. The present Farm Bill (H.R. 2559) enacted June 20, 2000, provides more than $15 billion in aid to farmers over 5 years to increase crop insurance subsidies and to provide direct economic assistance to farmers.

The market for fermentation sugars is estimated to be 20 to 50 million tons for fuel ethanol production and 100 million tons for production of chemicals and plastics. *Replacing methyl tertiary butyl ether (MTBE) offers a 2-billion-gallon ethanol market. Octane enhancement can increase the market by another 1.5-4 billion gallons, according to a recent report by Downstream Alternatives (Reynolds, 2000). If stover captures 30%-60% of this potential, it requires 20-50 million tons. Fermentation sugar requirements for chemicals and plastics are estimated by NREL to exceed 100 million tons (NREL, 1999).*

Corn stover pulp has many of the same properties as hardwood pulp and may be used to replace hardwood fiber in the United States. The U.S. hardwood pulp market is 30 million tons. It may also be exported to meet the growing paper needs worldwide. Capturing a small portion of these markets is somewhat likely to occur in the next 5 years, depending on the process economics.

There is some concern among the corn growers and processors that an economic stover process could threaten the existing market for corn and corn ethanol. Other growers perceive it as a way to increase the total net per acre. They cite the recent study (USDA OEPNU 1999) that replacing the current MTBE market with ethanol increases the corn price $0.14/bu. *A comparison of the gain from corn to corn stover sales is shown in Table 6. Stover benefit is based on a sales price of $40/dry ton and deducting the cost for custom baling at $15/dry ton. It does not include transportation from the field to the processing facility.*

Table 6. Relative Producer Benefit for Corn (and Corn Stover) Grower

Bushels per acre	130	170	200
Stover Revenue Increase	$56	$78	$93
Corn Revenue Increase	18	24	28
Stover Revenue over Corn	$38	$54	$65

1.6 Business Model

Because producers and processors are interdependent for success, several participants suggested the biomass business model include the producer as an equity owner with the processor, with both benefiting from improvements in harvesting and processing.

Logistics and transportation cost dictate that the processing plant be located near the stover supply. This model resolves the issue of harvest time purchase and storage of the feedstock by the processor , because the producer and biomass supplier can hold the inventory. Using a biomass supplier working with producers offers the processor off-site storage, just-in-time (JIT) delivery, and eliminates the impact on the processor of carrying 9 to 14 months feedstock inventory as working capital.

The Heartland Fibers business model—which was unsuccessful—premised a no-cost feedstock, with the harvest benefits and revenue sharing for the producer outweighing the baling cost. As an alternative, some thought that during the start-up of a new processing location, the producer might initially choose to supply feedstock in exchange for equity, deferring payment until the plant was in operation. This improves the project cash flow and reduces investor risk while providing a share in the value-added processing to the producer.

The potential carbon credit value for processing the biomass is another factor that encourages the producer and the processor to join together. If the current forecast of $10 per ton of carbon minimum credit were realized, a plant consuming 1,000 tons of corn stover per day would benefit by $2.5 million annually.

2.0 PLANT SCIENCE COMPANIES

Key Issues: Corn Hybrids

- **Produce more biomass** that can improve the productivity of the total crop—grain and stover

- **Increase yield from biomass** by improving the cellulose portion and reducing the lignin

- **Co-produce other products**, e.g. cellulase enzymes that can enhance the process economics or other co-products that add value to the recovered crop

- **Improve plant properties** for enhanced fermentation sugar and agri-pulp production

2.1 Producing More Biomass

Increasing the stover makes more available for harvest. This reverses the trend to reduce the relative amount of stover to grain. Residue management issues now make it desirable to minimize the stover production relative to the grain, except for silage, for which total production per acre is one of the desired characteristics. The current ratio is close to 1:1 for the grain hybrids. The ratio for silage hybrids is not one of the parameters measured, just the total silage yield.

Removing the stover avoids the present problems incurred with excess surface stover.

The new measure of performance becomes net value of the sum of the corn, plus the biomass removed.

2.2 Increasing the Yield

Increasing the amount of sugars produced and reducing the amount of lignin in the corn plant can enhance economic viability of a lignocellulosic processing facility. Plant Science Companies may add value to the crop by increasing the cellulose and reducing the lignin composition. Cellulose-derived products--fermentation sugars and pulp--generally have a higher value than products from lignin.

Lignin represents about 20% of the total stover. Processing 30% of the total stover produces 14 million tons of lignin. This greatly exceeds the total worldwide market for unmodified lignins, estimated to be about 4 million tons. The remainder has a fuel value.

A previous study by Broin & Associates, Vogelbusch USA (2000) and Anklam & Associates for NREL (1996) reported that the Otter Tail Power company's Big Stone Power Plant would burn 40% lignin cake from the centrifuge up to 7% of its coal burn. The agreed-upon price was $0.50 per million British thermal units (Btus), FOB their plant. On a dry basis, the lignin was valued at $11.43 per ton by the power company. Dry lignin contains 11,800 Btu per pound. The power plant was more concerned with the handling characteristics of the lignin than its moisture.

In a recent study the fuel value for lignin was determined using the ASPEN+™ model and found to be worth about 85% of the feedstock price, e.g., if the feedstock is $35/dry ton then the lignin is worth $30/dry ton, just for its lower heating value (Wooley, 2000).

Lignin adds strength to the plant. Lignin can be reduced by earlier harvest because it develops at the end of the plant life cycle. It can also be reduced by selective breeding--borrowing traits from corn silage hybrids. Silage contains less lignin. *Lignin has been reduced 45% in aspen, increasing the cellulose content 15%. No decrease in structural integrity was observed (Chiang et. al. 1998).*

2.3 Co-Products

Several plant science companies are currently using the corn plant to develop production of vaccines, nutraceuticals and enzyme production. Protease enzymes have already been commercially produced in plants (Patent No. US 6087558)[5]. The most promising route is expression of the gene in the grain where the environment is more stable. Attaining a concentration that may be economically recovered is a hurdle for some of these products.

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[5] E. Hood, co-inventor, attended the Lincoln, NE colloquy.

Producing cellulase enzymes where capital investment in fermentation processes and associated operating costs would not be required was thought to be an attractive possibility. The corn kernel can hold a “cocktail” of enzymes. However, the cellulase system and plant system complexity makes it a more difficult assignment. One problem is to get the correct ratio of proteins in the seed. Once expressed, it is very stable. The consensus was that it is not likely to occur within the next 5 years.

2.4 Improved Plant Properties

Several changes in the corn stalk can ease its processing to sugars and improve the pulp quality. Both approaches are thought to have potential. Increasing the ratio of a feedstock with a ratio of arabinoxylan to total nonstarch polysaccharides (AX/NSP) of greater than about 0.39, improves the accessibility of the cellulose for hydrolysis when the pentose sugars are removed (Patent No. US 6090595).[6]

Enhanced fiber strength, varied colors, and improved processing properties were mentioned. The tree and cotton plant programs may provide an initial platform. A more dense plant is also desired to reduce transportation costs.

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[6] J. Tolan, co-inventor, attended the Bloomington colloquy.

3.0 BIOMASS SUPPLIERS

Key Issues: Corn Stover Supply

- **Procurement** of enough feedstock to supply a 1,000- to 2,000-on-per-day plant requires experienced people that have credibility with the producers and processors.

- **Logistics** skills are key for coordination during the harvest and insuring JIT delivery to the processor.

- **Harvest** of the corn stover requires a large number of balers, supporting equipment, and skilled operators to collect the material during the short harvest window.

- **Storage** of the stover is necessary to ensure minimal degradation, protect it from weather, and minimize fire risk.

- **Transportation** of the bulky material—8 to 9 lbs per cubic foot—requires some specialized equipment to minimize handling cost.

- **A Business Model** is needed for the biomass supplier in conjunction with the producer and the processor to hedge prices and further reduce risk.

3.1 Procurement

A relatively small ethanol plant producing 30 million gallons of ethanol per year requires 350,000 tons of biomass--about 1,000 tons per day. When a market is established, there is much confidence that 1 million tons of corn stover can be readily harvested within a 50-mile radius in multiple locations. The radius is expected to decrease to 35 miles within 5 years. Specific examples in which a 50-mile radius can exceed the assumption were cited, based on harvesting 1/3 of the crop:

- Mendota, IL, 1.9 million acres of corn supplies 3 million tons
- Harlan, IA, 1.2 million acres of corn supplies 2 million tons
- Kearney, NE, 1.6 million acres of corn supplies 2.7 million tons

Procuring feedstocks other than corn stover are desired for diversity--and this is a difficult challenge. Corn is the most productive plant grown in the corn belt. Where corn yields are highest, the land value requires cash crops to be grown, so the choices for other crops are relatively narrow, currently limited to soybean-corn rotation. Adding other crops in the rotation may be an attractive option as the market demand for biomass grows, but this is not expected in the next 5 years.

Soybean stubble is one option, because most corn is grown in a soybean-corn rotation. The quantity per acre is less, about 1.5 dry tons per acre based on a ratio of 1.5:1 for stubble to bean and an average yield of 40 bu/acre. *Analysis of the stubble shows it is about the same composition as corn stover (Ruiz and Templeton, 1998).*

The stubble can be harvested earlier than corn, increasing equipment utilization. The impact of removing the stubble on the soil becomes an important consideration. It has a C/N ratio about half that of corn stover and therefore decomposes at a faster rate when left on the surface. Additional study of removal’s impact on the soil is recommended before including a significant portion of soybean stubble as a feedstock.

Organizing stover procurement for just one product is thought by some to be more difficult than when there are more uses. Multiple products spread the risk and ensure adequate outlets for the feedstock. For example, separating cobs from the stover and the pith from the stalks, fermenting the hemicellulose sugars, and processing the fibers to agri-pulp diversifies the market.

The harvest window for the annual supply is usually less than 80 days. Based on experience from obtaining smaller quantities, it is most likely that biomass suppliers will perform these tasks with custom operators, not with the producer or the processor.

Producers are time-pressured to harvest the grain. There is no slack allowed for harvesting the residue until the cash grain crop is safely collected—by then field conditions may limit the quantities because of weather and down stalks. In 1996 Great Lakes Chemical Company was unsuccessful in its attempt to get delivery of baled corn stover from the producers in spite of obtaining their earlier commitment. At the end of the cash-grain harvest, field conditions had deteriorated some, but most simply declined for other reasons.

After this initial attempt failed, Great Lakes Chemicals retained a biomass supplier that obtained more than 400 written commitments from producers that allowed them to remove corn stover from 50,000 acres the next year. The biomass supplier contracted additional custom operators to supplement its harvesting and collection resources. The collection was a big success. The company received feedstock in excess of its needs. A waiting list for both producers and custom operators was established.

Other examples of successful large-scale stover and straw collection include Isoboard and Dickey Environmental. Isoboard is a particleboard manufacturer that uses wheat straw in Manitoba, Canada. The company chose to use its employees and harvest equipment for its initial plant in Manitoba due to lack of local infrastructure. Dickey Environmental chose to use a combination of biomass suppliers and their in-house group to operate the collection equipment. Based on the success of biomass suppliers, the colloquy participants expect future processor locations to outsource this activity.

Procuring feedstock to supply a 1,000-ton-per-day plant is a sizable task—about 2,500 fields and 100 balers are required. The number of purchasing agreements is likely to exceed 1,000.

Effectively establishing the infrastructure to carry this out requires an experienced, flexible, well trained organization with proper equipment and excellent communication and administration skills. The biomass supplier must establish and maintain credibility with both the processors and the producers.

3.2 Logistics

Maintaining high equipment utilization is key to meet schedules and control costs. The harvesting window is affected by the area to be harvested. A 35-mile radius has just half the area of a 50-mile radius.

The larger area allows more flexibility to assign equipment at the start of the harvest and when local weather conditions are just partially favorable.

Close coordination of the stover harvest with the grain harvest is needed to track field availability early in the harvesting process. Prompt removal from the field is required to comply with producer needs. Some farmers plant a cover crop, others apply a fall fertilizer treatment or add other activities, such as grazing cattle to pick up any dropped corn.

Field conditions must be continuously monitored to ensure stover moisture meets specification and soil compaction is minimal. Early in the season, a minimum of 3 days is usually required for the stover to drop to 30% moisture or less after the corn harvest. Rain and humid conditions are often local, and equipment can be shifted to acceptable fields.

Multiple storage areas must be arranged prior to minimize the risk from fires. Equipment fuel and maintenance, baling supplies, and experienced personnel must be provided.

In addition to the harvest, delivering the feedstock to the processor as needed requires considerable loading and transportation equipment. Delivering 1,000 tons per day of corn stover requires approximately 100 truck deliveries for round bales or 70 for large square bales. However, many existing corn processors restrict delivery times to reduce plant staffing requirements. For a 5-day delivery, unloading during just 12 hours requires delivery of nearly 20 trucks per hour.

3.3 Harvesting Corn Stover

Corn stover baling is not widely practiced, relative to forage crops and wheat straw. The small amount baled is used for feed supplement and bedding. Most bales are not transported off the farm. If sold, it is often by the bale and "as is." Using biomass as a feedstock requires additional harvesting requirements and product specifications.

The producers require that the stover be harvested in a timely manner, leaving a clean, even field that complies with conservation requirements. Soil compaction should be minimal, and the operation should be free of any surprises.

The processors require a clean, low-cost, consistent product that meets their requirements. Moisture and dry bulk density are the most important specifications, with low dirt content also a key concern for feedstock. For agri-pulp, cobs cause quality and processing problems. They desire a cob-free material. Processors are also concerned with plastic wrap disposition from round bales.

For legume and grass crops for cattle feed materials, moisture content should be in the range of 14% -16%. Otherwise, heating and molding can occur, both detrimental to the value of bales for feed or for biomass. At moisture content levels of 25%-30% there is risk of extreme heating or even fire. An additional challenge is that moisture is not homogeneous, i.e., there will be localized places where the moisture is much higher.

Corn stover is a bit more tolerant due to its coarse structure. Moisture should be around 20% for best results. Low values result in excessive dust loss that is a nuisance. Baling 30% moisture material is the upper limit without serious risk of material degradation. Some have baled material as high as 40% moisture and the results have been satisfactory after they allowed the bale to "cure" before stacking.

Excess moisture must be allowed to breath out of the bales before storage in close quarters. Over a 2-8-week period, these bales come to equilibrium moisture of about 16% -18%, depending on ambient conditions. During this time, the bales need to be situated so that the moisture can migrate out of the bales. This adds another challenge to managing the operation overall. In addition, high density is important for efficient harvest, handling, and storage. However, the higher the density, the more difficult it is for moisture to migrate out. One of the big problems with moisture is that there is no good way to measure it. The material is not homogeneous. Most producers use a portable conductive type moisture sensor. These devices are approximate at best and not accurate enough to "push the limits" on moisture content. As a result, stover is baled when the stover is measured at 20% moisture whenever possible.

The most accurate way to measure moisture is by weight using a drying oven. This is not very practical for most producers. More accurate moisture measurements are needed to permit baling closer to the maximum.

Only the *dry* bulk density of bales is meaningful for feedstock quality. Bales need to achieve a dry bulk density approaching 9 lbs/cubic foot for storage stability and low-cost transportation. Lower densities result in shifting storage stacks, low productivity due to the extra handling, higher wrap and transportation costs, and greater loss in storage. "As is" bulk density of bales can be caused by excessive dirt and high moisture. Silage has a dry bulk density of about 3 lbs/cubic foot. Table 7 summarizes typical moisture and density values:

Table 7. Collected Corn Stover Bulk Density

Form	As Is Density lbs/ft^3 [a]	**Moisture %**	Dry Lbs lbs/ft^3
Round	9 -10	15—30	8
Square	11-12	15—30	9
Silage	5	45—65	3

[a] pounds per cubic foot

Participants discussed five collection methods and three collection forms.

3.3.1 Collection Methods

Field collection methods were discussed:

- Whole-crop harvest
- Flailing and then raking the residue into a windrow immediately before baling
- Raking without flailing
- Picking up a windrow left by turning off the spreader on the combine
- Baling without any other field operation

Each can be best for a particular set of conditions. Whole-crop harvest is performed near Blairstown, IA, for Sunrise Energy using a forage harvestor. The other methods were used for large-scale harvest near Harlan, IA; Sharon, WI; and Central Illinois for the production of furfural and premium horse bedding.

Whole-crop harvest, including the corn, solves the timing issue, delivers a clean product, and lowers the collection cost if not transported long distances. Running over the stover with the combine is unavoidable in the other cases. Collecting this material results in the inclusion of considerable dirt.

Moisture of the composite material should be between 50% and 65% for best ensilage results. Compaction is less, because only one pass is required across the field. Present forage equipment does not separate the plant components. It is most suitable for whole-crop processing, for example, when the crop including the corn is processed to fermentation sugars and fermentation ethanol—as at the Sunrise Energy plant.

The corn harvest usually begins when the corn has matured, but still high in moisture, above 20%. The stalk is normally 15%-20% higher than the corn at this stage. To speed the stover drying process, the stover is flailed--chopped with a freely swinging bar--and spread out evenly in the field. While this adds another step, it shortens the harvest window, better insuring a complete harvest. Some flail regardless--especially those with high yields--to better manage the heavy residue, as whole stalks can interfere with the future field operations.

After the stover dries—normally 2-4 days--it may or may not be raked. Raking results in the maximum stover harvest, between 2 -4 tons per acre. The windrow should be baled within hours of being raked to avoid the potential loss due to rain. The stover does not dry well in the windrow. If not collected before a rain, it may be lost due to high moisture content. Also, if not collected, the windrow causes a serious problem for the next crop.

When flailing or raking, care must be taken by the operator to always stay above the root crown. If either the flail or rake hits the crown, it is usually pulled out with the roots, bringing along a large clod of dirt that ends up in a bale.

Later in the corn harvest, and depending always on the weather, the stover dries to the point at which flailing is not necessary. Raking is always an option. A cleaner material can usually be obtained if the field is not flailed or raked, according to the participants.

Leaving the spreader turned off on the combine results in a windrow containing many cobs, leaves, and husks. The windrow is cleaner too, because it is discharged behind the combine. Baling this windrow typically removes 1.5 dry tons per acre. A separate raking is eliminated. This operation works well later in the corn harvest when the stalk is less than 30% moisture.

It is also common to bale directly on a dry field. Most balers for corn stover incorporate a built-in rake that can be adjusted to the desired height, giving the operator more control. A chopper is also incorporated in some cases to help increase the bale density–which is important when wrapping or transporting.

3.3.2 Collection Forms

Square bales, round bales, and chopped silage are all current possibilities for collecting corn stover. Square bales are preferred for commercial crops because their shape is easier to stack and more dense to ship. Round bales and silage usually stay on the farm or ranch.

Square bales are used mostly for forage crops such as hay and alfalfa, along with wheat and other cereal straws found in the plains and western states. Round balers are most common in the Mid West. Both round and square bales require skilled operators. Because there is little market for corn stover, few have much experience with it. Relative productivity is heavily dependent on the operator and field conditions. Square bales are readily transported long distances.

Round bales are more difficult to transport efficiently. Wheat is baled for animal bedding and feed supplements and is usually used for on-site consumption. Density for these bales is not a significant concern. When transported off site, density becomes a primary issue.

Round balers are more numerous in the United States, exceeding 100,000 units. They are less complex, but still require considerable skill to operate. Some are now used in the corn belt for baling stover, which is then used for animal bedding and as a feed ingredient. The bales may be wrapped with a plastic net or with twine. Plastic mesh wrap allows baling at 15% to 30% faster, but it adds about $3 per bale and must be removed before processing in most applications. Devices exist to perform this task, but disposing of the plastic may be a problem. Using sisal twine eliminates the mesh disposal problem because it can be processed with the stover. For round bales, the baling productivity drops when the twine is used, remaining at $15 per dry ton.

Collecting the stalks in chopped form requires the least operating expertise. This is practiced widely in Europe, but not in the United States. The same equipment used for silage can be used to harvest the stalks.

Present baling price is about $15 per dry ton for bales left in the field without transportation. Payment on a dry ton basis is preferred over an “as is” per bale price.

Baler utilization is often less than 300 hours per year. Increasing equipment use by harvesting more crops will lower costs. Alfalfa, soybean stubble, and switchgrass were often suggested because the harvest times are different. Traveling to other areas, going from south to north as the crop matures, is another possibility.

The primary producer issues associated with field collection are timely harvest, minimal soil compaction, leaving an even cover for erosion control, and no evidence of broken bales. The timely harvest permits other fall field activities to be completed. Harvesting equipment should minimize soil compaction. A consistent cover better ensures an even harvest of the next crop.

3.4 Storage

Feedstock storage is required until the next crop is harvested, normally 9 months later. In addition, some reserve is needed as a contingency to ensure adequate feedstock for processing. The material requires a large space, must be protected from the weather, and handling should be minimal.

An estimated 250,000 - 300,000 acres are required to supply a 350,000-ton-per-year plant. During harvest, material is likely to be delivered directly to the plant to minimize handling. Normally a 5-day supply maintained on the plant site should be adequate. The remainder will likely be stored in five to ten sites within the 50-mile radius. Spreading out the sites reduces the risk of fire.

No cases of spontaneous combustion of corn stover are known to have occurred. Unlike small cereal straws, the stover is less homogeneous. However, under the "right" conditions it is possible to self ignite. Also, lightning and other ignition sources exist and adequate precautions must be taken to minimize the fire risk.

A clean, well-drained surface is desirable. If not, the bottom layer may rot or contain too much foreign material to be processed. Easy access to the site is desired for removal and trans-shipment to the processing facility during the year.

Stacked square bales must be covered or placed under a roof to avoid moisture damage from snow and rain. Round bales wick the rain and melting snow away, and cover is not required. However, the relative shrinkage of sheltered round bales to those not sheltered is not known.

Bales can be stacked and stored for more than 2 years without significant change in composition (Templeton et. al., 2000). The amount of shrinkage depends on the storage time, temperature, moisture, and storage conditions--with normal loss estimated to be 15%-30%.

Square-bale stacks require consistently made bales. Square bales expand with time, in a direction and amount dependent on its history. They are also compressed in the stack. Unless the bales are similarly made and properly stacked, the stack will shift or topple over. If not detected and restacked, the material may be lost to decomposition.

Round-bale stacks are stable and do not have the same compression-expansion problem. However, they do not retain their shape as well as square bales, making trans-shipment more difficult.

3.5 Transportation

Transportation costs are a major factor due to inherently low bulk density. Table 8 shows the fee schedule for the Great Lakes Chemicals project (Glassner et. al. 1998). Due to the shrinking amount paid to the producer, and the increasing cost of shipping, biomass feedstock collection is normally considered to be within a 50-mile radius of the processing center.

Table 8. Corn Stover Pricing, Delivered to Processor

Payments, Dollars per Dry Ton				
Radius, Miles	0-15	16-30	31-50	51-100
Producers Revenue	$15.00	$12.33	$ 9.66	$ 7.00
Baler's Revenue	$14.60	$14.60	$14.60	$14.60
Hauler's Revenue	$ 6.10	$ 8.77	$11.44	$14.10
Total Delivered Cost	$35.70	$35.70	$35.70	$35.70

High bale density is required to minimize hauling costs. For the same project, Table 9 shows the payment received for round bales per trip. The standard density was 1,200 dry lbs. Achieving a higher density resulted in a payment of more than $2 per mile for short distances. If the density was low, payment could be less than the operating costs.

Table 9. Bale Density Related to Hauling Revenue

	Payment Per Loaded Trip*					
Trailer Weight, Tons	7.65	8.50	9.35	10.20	11.05	11.90
Dry Bale Weight	900	1,000	1,100	1,200	1,300	1,400
0-15 miles	$47	$52	$57	$62	$67	$73
16-30 miles	$67	$75	$82	$89	$97	$104
31-50	$88	$97	$107	$117	$126	$136

*Normal load for inland trailer is 17 round bales per load, 6+6+5 Bales

Handling the product just once is ideal--from the field to the processing center. Because on-field storage is not possible year round, multiple handling is required. Nearly all producers want the fields cleared of bales shortly after harvest. Square bales are often stored nearby, in a tarp-covered stack. Constructing the stack can be simple, using special equipment that travels around the field collecting five bales, and then depositing them, aligning them in a 5- to 10-bale-high stack (20-40 feet) with as many rows as desired, or under a sheltered building for later delivery to the processing center.

In other situations, the bales are loaded directly onto a semi-trailer for transportation to their destination. Often, the baling cost includes this service. For example, one participant quoted $24 per dry ton for large 4-foot x 4-foot x 8-foot square bales loaded directly, using a fork truck they supplied.

In large harvesting efforts, round bales are removed from the field with “load-and-go” wagons. The driver/operator picks up the bales with an extendable arm. Loading 17 bales requires less than 20 minutes. The wagon is pulled with a high-speed tractor capable of speeds up to 55 miles per hour (mph) to the processing center. At the center, the load is sampled for moisture, weighed, and self unloaded in less than 10 minutes.

Forage-type collection of high moisture corn stover, and ensiling it, may be more economical when close to the collection center even with the higher moisture. Shrinkage is less than that for bales when properly stored. The fire hazard is avoided, and tractors may be used exclusively.

Tractors are less costly than trucks for shorter distances. They are less regulated and the insurance cost is less. Transportation of round bales within a 35-mile radius is considered most cost-effective, especially when hauled by high-speed tractors—JCBs and UNIMOGS--that can travel safely at 45- 55 mph. Beyond 35 miles, trucks and square bales begin to be favored.

3.6 Collection Business Model

Procuring the required amount of biomass is a major task, and is likely performed by a middleman, referred to here as the biomass supplier. Using the grain elevator business as a model, the biomass supplier assumes the risk to provide the required feedstock.

Alliances between the biomass supplier and local producer organizations, such as Central Illinois Fibers Association and Iowa Quality Producers Alliance, are expected to be formed to facilitate large-scale harvest. Kearny Area Agricultural Producers Association (KAAPA) has already organized in this manner as a result of working with Heartland Fibers. As mentioned earlier, if these producers and the processor enter a win-win agreement for equity participation in exchange for feedstock, the venture risk is further lessened.

Linking suppliers in diverse geographic areas was proposed to better ensure that local feedstock requirements are met in the event of crop failure or resource shortage. Another supplier from an area not affected can pick up the material to meet the shortage. Equipment essential for the harvest can be dispatched as required. While transportation costs will be more, feedstock can be supplemented from another area to keep the processor fully supplied. The supplier linking can also speed learning by exchanging collection improvements. The improvements can be transferred rapidly, quickly enacted, and costs would thus decline as productivity increases.

Some see the possibility that a futures market for corn stover bales could emerge to hedge feedstock pricing. Carbon credit trading, if more widely established, could help make the bale trading a reality.

4.0 AG MACHINERY MANUFACTURERS

Key Issues

- **Clean Stover Collection** is required to prevent storage deterioration and avoid processing problems

- **Lower Cost of Collection** to improve economics can be best accomplished by reducing the number of field operations, eliminating baling or reducing it further, increasing density, reducing handling and transportation cost

- **Shortening the Collection Window** will help ensure the harvest is complete with a single-crop harvest if it can be as fast as current grain harvest.

- **Minimizing Soil Compaction** can be achieved by reducing the number of field operations.

- **Consistent Regulation** permits safe equipment utilization across borders and does not penalize collection of excess stover.

4.1 Clean Stover Collection

Clean stover is desired to avoid excess dirt in the collection process. The additional wear and tear on equipment is substantial. Baling and hauling dirt just adds cost and excess dirt can be a source of microorganisms that can accelerate spoilage in storage.

Running the combine through the field inevitably presses some of the stover into the soil. It must be left behind or washed in the first stages of the process. Leaving foreign matter in the field is everyone's desire.

Collecting standing stalks produces the best results. Equipment now exists in Europe that harvests corn and stalks with one pass. Currently, it shortens the harvest window for stalks, but lengthens the cash-crop harvest. The equipment can likely be adapted to the U.S. market's need to speed the harvest. Still, moisture differences between stover and corn, and the need to harvest corn early likely prevent this from becoming a universal solution.

One mode of operation suggested is to begin the corn-stover harvest in the area closest to the collection center where ensilage is economic. As the total crop dries, adapt the operation to the one-pass method for the lower moisture material, compressing it for economic transportation.

Existing equipment may also be modified to better ensure flails and rakes are operated within the desired height to minimize dirty stover. Self-adjusting systems that sense the proper level may be one solution, minimizing the need for frequent operator adjustments or the possibility for operator error. While uneven ground may limit performance in some areas, a cleaner and potentially larger collection is likely.

4.2 Lower Cost of Collection

Stover collection cost is a function of the producer's "fair price", the harvest cost — usually the baling cost — and the cost of storage, handling, and hauling. Table 8 shows baling represents nearly 40% of the total, with the producer and hauler receiving the remainder.

Eliminating the baling with one-pass harvest results in a large cost improvement but does not fit all situations because of the low bulk density. Improving the operation of existing equipment to enable all required operations to occur in just two passes is a large step towards cost reduction. Baler improvements could include an automatically controlled rake to better select the desired material--in some cases just the top, and in others as much as can be collected without hitting the crown.

Adapting the combine to optionally chop more of the stalk--discharging all material behind it in a flailed form--eliminates one pass through the field with the flailer. Running over it with the combine is avoided and the flailed material will dry faster.

Cobs that are separated from the grain in the combine could be collected and sold as a higher-value product instead of being spread back on the field. Both chopping and cob separation would need to be accomplished without slowing the grain harvest performance.

Greater bulk density is always desired to lower transportation and wrap cost. In addition to a more dense plant produced via plant science, a denser bale can be obtained if more pressure is applied. An optional chopper after the stover pick-up to reduce the stalk particle size is also conducive to more dense bales. A doubling of the density so that 17 round bales come close to the load limit of 40,000 lbs reduces the hauling cost nearly 30%-50% depending on the distance.

Simpler equipment that requires less maintenance, is easier to operate and maintain, is desired. Better wrapping methods that do not slow operation and can be processed are desired for balers.

Two questions arise.

1. Is field densification of biomass, similar to what is done with cotton, appropriate?

- Harvest the corn and stover with a single pass.
- Transferred to trailers in the field for transport to dryer or to storage.
- Collected and chopped corn stover is transported to field edge and compressed in large container similar to cotton.

2. Can other transportation modes be effective?

- Slurry systems that have very high solids content, using pipelines similar to hydro mulch, may be employed to convey the harvested biomass to the collection center.
- Dirigibles may be effective for longer distances.

4.3 Shorten Collection Window

Longer term, at least two scenarios can emerge to shorten the stover window--a single-crop harvest using radically different equipment, and a mobile, organized group of custom balers that work to extend the existing technology.

- The first group will develop new methods to go with the different equipment. These include the following.
- Whole fields are bought for the total plant harvest
- Payment is based on a formula that estimates value
- The field is harvested by others
- Corn is separated in a different way, then dried, stored, and sold in existing channels or sold with identity preservation

Other components, cob, stalk, leaves, and husk are now available for disposition

The latter, using improved versions of current equipment and adapting procedures can collect the major portion over the next 5 years. They would be gradually replaced with new equipment and methods as their economic life is exhausted. The scenarios are likely to develop together as the collection market grows.

4.4 Minimal Soil Compaction

Soil compaction reduces the yield by inhibiting nutrient flow and good root development. The degree of compaction varies with soil type and tilling practices. No-till soil is the most resilient, other factors being equal. Freeze-thaw cycles help restore lower soil bulk density. Tillage is another method to overcome compaction. With the incentives to move to less tillage, compaction is an increasing concern to some.

To avoid compaction, equipment traffic in the field should be kept to a minimum. Some follow a path between the rows, as in ridge till. Others use special tires that are designed to spread the load over a large surface area.

Picking up the total crop should be done in a manner that minimizes compaction. A single pass is the most desirable. With one pass, wide tires can be employed without concern of running over much of the stalks and reducing the amount of clean stover that can be harvested.

4.5 Consistent Regulation

More liberal and consistent state regulations are needed for load limits, dimensions, and operation rules that can safely lower transportation cost for transporting the material. Iowa has already made changes, but more are required by other states. Efforts should be coordinated with Canadian officials to better ensure equipment can readily cross borders. Equipment utilization is expected to increase. The outcome will be safer operation at lower cost.

Collection of excess stover should be considered in policies that are intended to encourage no-till and conservation-till methods. While it is important to leave adequate stover on the surface to prevent erosion, leaving *all* of it hampers some operations as mentioned earlier.

5.0 ENZYME SUPPLIERS

Key Issues

- **Economic Enzyme Hydrolysis** is required to reduce the cost of fermentation sugars to 3¢-4¢ per pound and lower fuel ethanol cost from an estimated 30¢-50¢ per gallon to 5¢-10¢ per gallon.

- **An Economic Process** for the remainder is also needed that includes pretreatment gives high yields, and incurs low capital costs.

- **Market Development** is a high risk.

5.1 Economic Enzyme Hydrolysis

The cost of cellulosic enzyme hydrolysis continues to be a major economic hurdle. A previous study found the cost to be 50¢ per gallon of ethanol, *but* the cost could be reduced to 5¢ per gallon with an investment of 25-50 Full Time Equivalents (FTE) researchers (Glassner and Hettenhaus 1997).

There was consensus that the tools exist to improve enzyme performance by five to ten times. However, the large investment increases the risk. In some cases customers are willing to fund this work and share the risk. This is not the case for biomass, which significantly increases the risk of enzyme companies to undertake the development cost on their own.

The process stream for the cellulase enzyme conversion can vary, increasing the uncertainty of the outcome. Though there is a large amount of biomass composition similarity, the initial hydrolysis treatment can result in the formation of a wide variety of other materials such as acetic acid, furfural, esters, and ketones that can act as inhibitors. Many hydrolysis process variations have been applied to different feedstocks. The removal of inhibitors formed in this step can be expensive, and their presence can inhibit enzyme performance. Some resistance to inhibition can be designed into the enzyme structure, but at additional cost. Successful development requires a joint study of the hydrolysis process and enzyme performance.

5.2 Economic Process

Even if the enzyme hydrolysis improvement is successful, the participants expressed concern about whether the total process will be economic or not. Yields from the fermentation sugars are important. Though glucose is readily converted, pentose sugars are more difficult. At least four recombinant fermentation strains are available—none have been demonstrated on a commercial scale. Like enzymes, their performance can also be inhibited by materials formed during hydrolysis. Iogen has targeted 80% xylose conversion.

Disposition of the large amount of gypsum formed from sulfuric acid hydrolysis was a concern, along with the complexity of ion exchange used to clean process streams after acid hydrolysis. Both are thought to contribute to the relatively high capital and operating cost compared to existing to corn ethanol plants, and need to be reduced.

Co-product values from the stover may improve the economic picture. Cobs and agri-pulp are promising—others are either small niche markets, such as hydro-mulch for fiber, or yet unproven, such as lactic acid for plastics.

5.3 Enzyme Market Development

There is some interest emerging from customers in using biomass. For example, the existing corn ethanol industry and the corn refining industry have extensive experience with enzymes for starch applications. Most have looked at corn fiber processing requiring cellulase enzymes, but the relative difficulty in conversion of the cellulose results in more than 30 times more enzyme at present than for an equivalent amount of starch. In addition, the small corn fiber market, just 4 million tons total, would not justify the required enzyme development cost.

A larger market, such as the one for agricultural residues, is needed for economic justification of the effort required to improve the enzyme performance 5 to 10 fold. *For example, converting just 30% of the available corn stover, 80 million tons, offers a $400 million market if enzyme performance is improved 10 fold, and sold at 5¢ per gallon of ethanol. Converting all of the corn fiber generates just $17 million in revenue.*

6.0 PROCESS ENGINEERING COMPANIES

Key Issues

- **Process Economics** generally require improvement.
- **Process Technology Validation** is needed on a commercial scale.
- **Project Financing** remains elusive due to high risk relative to rewards.

6.1 Process Economics

There are many approaches for biomass processing. Some appear close to commercialization, but none have been demonstrated. These include concentrated acid by Arkenol and Masada, dilute acid by BC International, and acid-enzyme hydrolysis by Iogen. Acid process technology is mature, having less improvement possibility than those based on biotechnology. Biotechnology advances are expected to lower enzyme costs and increase yields, offering more upside for economic improvement.

Upon completing a recent feasibility study for a 1,000-dry-ton–per-day biomass to ethanol plant, a process engineering firm found the process economics still required improvement. However, they saw the outlook as a ”Tremendous Opportunity” based on their previous experience with improving the corn dry milling plants (Vogelbusch, 2000).

In 1980 the installed capital cost of corn-to-ethanol plants was $3.00 to $3.50 per gallon This has been reduced to $1.20 to $1.80 for present corn dry milling plants, depending on size and infrastructure. A similar outcome is expected for biomass.

Participants were in general agreement that process economics can be improved and commercialization could be demonstrated within the next 2 to 5 years.

6.2 Process Technology Validation

Process design data is still emerging for biomass conversion, especially for the hydrolysis and fermentation processes. Most data has been derived from pilot plants with a capacity of up to 1 ton per day. Most are much smaller and are not fully integrated and operated intermittently. There are major voids in the data required to scale up to a commercial scale, estimated to be 1,000 fold or more. Also, these pilot plants are expensive to operate, being staffed by engineers, technicians, and scientists.

To validate this process technology for a commercial project design, data from equipment that is scaled much closer to full size is required. The process equipment needs to be integrated and operated continuously to finalize design and provide assurance that the plant will perform as expected. The operating costs are even more expensive than pilot plants. Unless they can be linked into an existing operation or a high value-added product can offset some of this cost, it is unlikely that they will be privately funded.

Iogen has constructed a single-train process for straw, switchgrass, and corn stover conversion to ethanol on the site of its' enzyme plant. With a capacity of 50 tons per day, designing a 1,000- to 2,000-ton-per-day plant--a factor of 20 to 40—can be done with a high level of confidence. Most of the increased production is accomplished by constructing multiples of the equipment installed in the existing single-train.

The cost of the demonstration plant is $25 million CN. The fermentation sugars produced are expected to be used for enzyme production along with ethanol, and thereby pay its way. The demonstration plant can operate for extended periods to collect the required data for analysis without draining cash flow.

During the colloquies, a route for existing dry mill plants was identified to co-process corn stover--using a dilute acid hydrolysis to convert a portion of the sugars in the DDGS or a “quick-germ” process on the front end and adding enough corn stover to maintain 26% protein. A preliminary analysis indicates promise and it warrants further study.

A 5%-10% jump in production comes from converting just 25% of the sugars. Most significantly, it appears to offer a cost-effective route to process validation for corn stover processing 50 tons per day. The co-production is more completely described in the next section.

6.3 Project Financing

Project financing is primarily contingent on demonstrated technology, promising market expectations, and attractive returns. The amount required is also a factor, with smaller amounts easier to obtain for risky projects. As a result, project financing for biomass projects to produce ethanol is a most difficult hurdle.

Project cost is in excess of $100 million. Borrowing a significant portion of the amount is viewed as a high risk because the technology validation is incomplete. Equity funding on this scale is equally difficult. The market for fuel ethanol can be disrupted by regulatory actions, government policies, or the Organization of Petroleum Exporting Countries (OPEC) increasing production, depressing prices at any time during the project life. Economic returns are relatively unattractive compared to other opportunities.

The markets for fuel ethanol are dependent on legislation related to clean air regulations, and federal and state subsidies. The associated uncertainty slows commitment by some until either the process economics do not require subsidies and/or there is increased confidence in a favorable legislative outcome. For example, the subsidy for ethanol is set to expire in 2007. Project payout based on continuing the subsidy beyond that date is not known. Other regulatory issues related to fuels can be revised, affecting the market size. Some issues, like moving to costing externalities are positive. Others such as issuing waivers to oxygenated fuel requirements are negative.

OPEC and oil industry actions are also not predictable. While oil prices are expected to increase with time, increasing the flow of existing reserves can drop the price at any time. The oil industry has seen ethanol as a potential threat to their refined products, potentially reducing their market share. Revising the refinery output mix to overcome any increased bio-ethanol challenge is always a possibility.

Several suggestions were offered to get more projects underway today:

- An Industry Consortium
- Government Loan Guarantees

6.3.1 Industry Consortium

Existing stakeholders could form a private industry consortium to construct a demonstration plant for its members. This requires resolution of many concerns including the following issues:

- Competing technologies—which would be selected and by whom?
- Anti-trust laws are an impediment
- Intellectual property ownership
- Required funding level is high relative to the industry's ability to pay

6.3.2 Government Loan Guarantees

When the first generation of corn-to-ethanol plants were constructed in the 1970s and early 1980s with Government Loan Guarantees, many technical approaches were used. All were economic failures--but they led to the next generations that are much improved and economic with the subsidy. As mentioned before, capital costs have declined 50%, from more than $3 per gallon to $1.50 per gallon. Process improvements have lowered operating costs and improved yields significantly.

Without the original loan guarantees, the present 1.5-billion-gallon fuel ethanol industry would likely not exist. Establishing a similar program for loan guarantees was considered the best route to validate the process technology and move the biomass industry commercialization ahead.

7.0 POTENTIAL PROCESSORS

Key Issues

- Co-Products, the Biorefinery Concept, may offer better overall economics
- Fermentation Sugars that are 40%-50% less costly, 3¢-4¢ per pound
- Ethanol produced from biomass that requires no more land use
- Chemicals produced from a less costly, “sustainable” source
- Agri-Pulp from corn stover that can replace hardwood pulp at less cost

7.1 Co-Products--The Biorefinery

While there have been many paper studies of biomass refineries, actual commercial biomass projects have mostly considered the final product, usually fuel ethanol or agri-pulp from biomass, with the lignin offering some energy value.

Co-processing the cellulose to fiber and the hemicellulose to fermentation sugars significantly improves the biomass revenue. Several participants indicated strong interest in co-locating a fiber processing facility adjacent to an existing ethanol plant that could process the fermentation sugars and use the lignin as a boiler fuel.

For a 1,000-dry-ton-per-day plant, converting the cellulose and hemicellulose to fuel ethanol generates $30 million annually, assuming $1 per gallon of ethanol. Producing mechanical pulp for further processing to paper products increases the revenue to $66 million. Producing paper with 90 brightness nearly triples the revenue to $88 million as shown in Table 10.

Table 10. POTENTAL REVENUE

Fuel Ethanol and Agri-Pulp Pro Forma Revenue, $million

1,000 dry ton/day, 350 days/yr

	Fuel Ethanol	Mechanical Pulp	90 Brightness
	$1/gal	$200/ton	$800/ton
Cellulose	$18	Mix	$70
Other Sugars	$12	Mix	$18
Total Revenue	$30	$66	$88

For co-production of ethanol and agri-pulp to work effectively, separating the fiber from the hemicellulosic fraction is key. Acid hydrolysis and depithing are suggested approaches. The hemicellulose sugars must be removed without shortening the fiber length or damaging the fiber branches. Acid can readily damage the fiber. Determining the process conditions that can accomplish the desired separation is expected to be difficult by some, and others saw it as an easier assignment. Depithing the fiber is a mechanical process that separates the fiber from other components. It is not as selective, leaving much of the hemicellulose with the fiber.

Additional benefits accrue if the lignin can be processed to higher value products or its fuel value extracted economically. The market for technical lignins is relatively small and the majority is likely to be burned for fuel, as previously discussed.

Acetic acid may also be recovered in small quantities, 1%-2% of the total feed. It can be an inhibitor to hydrolysis and fermentation if not removed.

Corncobs offer another co-product opportunity. Seed companies are the main source now. The market outlook for their use is favorable, with a value of $55-$60 or more per ton as is. Uses include industrial grinding, a carrier for pesticides and herbicides, kitty liter, and as a high-xylan source for processing to value-added products such as xylitol. Though cobs can be processed to fermentation sugars, they must be removed in the agri-pulp process to avoid weakening the product.

As a comparison, present corn-to-ethanol plants offset their processing costs by selling co-products. For dry mills, DDGS provides $0.35 per gallon credit based on a price of $100 per ton DDGS. Wet mills, which require more investment and have higher operating costs, obtain two to three times more credit from the sale of corn germ, its oil and cake, steepwater, corn gluten feed, and gluten meal. Carbon dioxide is sometimes collected and sold and/or used to increase the level in plant greenhouses. And several plants use process heat for aquaculture. The credits are relatively small, and can also be captured by biomass plants.

7.2 Fermentation Sugars

The ability to make many chemicals from fermentation products is well known. The economics for the carbohydrate route to most of these products is less favorable than using fossil fuels. With advances in biotechnology, the economic gap is being closed. It is expected that a sizable amount of chemicals, plastics, and fuel ethanol will be produced over the next 10 years. The primary driver is availability of low-cost sugars.

For example, corn stover and other agricultural residues can be converted to about 60% sugars when the cellulose (38%) and hemicellulose (32%) portions are combined. This is near the amount of fermentation sugars (65%-70%) derived from corn. Until recently, the inability to ferment hemicellulosic sugars gave them little value. Because the raw material cost is 50% less than corn, the potential for low-cost sugars has attracted interest from processors. NREL projects 3¢ per pound for sugars by 2010. The present cost of fermentation sugars from corn is estimated to be 6¢ per pound. Other advantages of agricultural residues include a substantial increase in feedstock with no more land use and that is not subject to the wide price fluctuations such as for corn.

Collecting and processing just 30% of the corn stover--80 million tons--produces 7-10 billion gallons of ethanol. Because there are no animal feed co-products from the stover, the feed market is not affected.

In contrast, if corn is used to increase ethanol production by 1.4 billion gallons to replace MTBE, the incremental 500 million bushels of corn produces 4.5 million tons of DDGS. When added to the existing 6.5 million tons now produced the DDGS market is disrupted (USDA OEPNU, 2000). Higher corn prices, about 14¢ per bu, cause feed use of other crops to increase, leading to price increases of other grains. Soybean prices are projected to decline by less than 1 percent. Higher corn prices reduce soybean production, but the decline in production is nearly offset by lower demand for soybean meal resulting from the increase in DDG production. Soybean oil prices increase in response to lower soybean production, but soybean meal prices fall in the face of increased competition in the protein feed market. The overall impact is considered small according to the study.

7.3 Agri-Pulp

Non-wood fibers are 9% of the total fiber supply for paper worldwide--about half is from agricultural residues. Crops grown specifically for pulp, such as kenaf and industrial hemp compose the remainder. In the United States, corn stover was used to make paper in the Midwest until the late 1920s, when the last mill was shut down in Danville, IL, due to economic and environmental problems. The U.S. pulp and paper industry shifted nearly exclusively to wood. Mills were located near the supply, and Ag-pulp use was discontinued, with the exception of cotton, hemp, and kenaf for niche markets.

The United States is the largest consumer and producer of pulp and paper products in the world. Pulp and paper mills cost in excess of $1 billion. Their chemical pulping processes are more than 100 years old. About 40% of the feedstock is from recycled paper. The other 60% is split between softwood and hardwood pulp. The majority of softwood is grown on industry-owned plantations. The processor largely purchases hardwood. *U.S. hardwood suppliers are under attack for mining forests, especially in the Southeastern part of the United States (Cubbage et al. 2000).*

A number of entrepreneurs are pursuing this market using corn stalks and improved processes. In contrast to wheat and bagasse, corn fiber is the same length as hardwood fiber. It also has an acceptable amount of silica--usually less than 2% after it is washed. While the stalk is less dense than wood, it cost less when transported short distances. Processing times are much less. For example, 35 minutes is required to pulp corn stover with one process compared to 6 hours for wood pulp, according to one participant, and fewer chemicals are required. The cost for a 1,000-ton-per-day feedstock plant is expected to be $50 million for unbleached product and up to $150 million for a bleached product.

Product samples prepared on a small scale have been tested and accepted by many potential customers pending their ability to deliver commercial quantities. Heartland Fibers has announced that 24 customers have approved their paper. The market is largely for dried pulp for sale to existing paper mills that are not integrated with pulp mills. About 200 exist, and most use recycled paper now.

Logistics is a problem to be dealt with because existing paper mills are largely located a distance from the corn belt. Most would require dry pulp, adding an extra step at both sites--one to dry the product, another to slurry it for the paper process.

CONCLUSIONS

The primary obstacle facing biomass commercialization according to the participants is validation of the process technology on a large scale, about 50 tons per day of feedstock. Without validation, project financing becomes a major hurdle unless loans are guaranteed.

Process validation on a large scale is expensive. It is likely that the validation trial will undergo several iterations requiring at least 4-6 months to evolve and reach an economic operating level. The high cost is best recovered by integrating the trial into an existing operation that can use the products and support the effort with resources already on site. Potential sites include the following:

- Existing fermentation plants, like Iogen's enzyme plant where process sugars can replace higher-cost, purchased feedstock
- Existing corn wet mills where corn fiber is already collected and an ethanol fermentation process is on site
- Existing dry-mill-to-ethanol plants
- Existing pulp mills for agri-pulp

Feedstock availability, collection, and storage are not expected to be an impediment with pricing in the $25-$40 per dry ton range delivered to the processor. Producers have real economic benefits to sell excess stover, adding $40 or more per acre income using a custom harvestor for baling.

Biomass suppliers have the expertise to deliver the large quantities needed. Existing harvesting equipment has been demonstrated to meet the feedstock price requirements with considerable room for improvement. In supplying the material for the trial, planning for a larger effort can be finalized for that location, including management practices that ensure soils are protected from erosion.

The market for fermentation sugars and for agri-pulp is expected to develop in pace with customer confidence that the suppliers can meet their needs. Gasoline blenders still recall when ethanol supplies withered as corn prices increased in 1995. Using other feedstocks not as sensitive to commodity markets is expected to assist acceptance.

Other conclusions include the following:

- Long-term impact for removal of agricultural residues requires further study.
- Past residue management practices can be overcome when a market develops for the residues.
- Plant sciences can improve biomass yield and enhance other properties by adapting existing plants in the next several crop years as a market for the "biomass" hybrid develops.
- Significant improvements in machinery, transportation, and storage can be made.
- Process performance can be improved most rapidly with a multi-disciplinary team working on an integrated process that includes pretreatment, enzyme hydrolysis, and fermentation.
- Enzyme improvements can be achieved that can lower the cost 10 times with expenditures of 25-50 FTE.
- Costing externalities such as GHG emissions enhances the economics for processing biomass significantly at $10 per ton of carbon equivalent.
- Co-processing corn stover to higher-value products is most likely--the biorefinery concept.

RECOMMENDATIONS

The conclusions led us to believe that DOE/NREL must take actions to work with potential processors of agricultural residues, particularly corn stover, and establish an objective to identify their needs and assist them to take the lead in organizing industrial involvement to implement demonstration project(s) that are in the 50-ton-per-day range to validate the process technology. The following activities are planned to help reach that objective:

Dry Mill Co-Processing

1. Meet with existing dry millers and review with them the co-processing opportunities to process corn stover to maintain 26% DDGS protein.

2. From the meetings formulate the support activities desired by them to take the lead in organizing industrial involvement and determine the resources required for implementation.

3. Review with others who are key for implementation, gain approval, and move ahead with periodic progress reviews.

In addition, the following activities largely underway now appear to be on course:

1. Feedstock harvest and collection improvements--Increasing density and reducing transportation cost should receive emphasis.

2. Stover storage stability study with B/MAP LLC--Consider expanding to include possible conditions required for spontaneous combustion

3. An ORNL/USDA ARS Corn Stover Work Plan needs to be created to better understand the effect of residue management practices on soils and the interactions of stover management and other aspects of crop production.

4. NREL use of corn stover feedstock in the PDU to obtain substrate and lignin samples for evaluation by others developing improved enzymes, agri-pulp, fermentation strains, and determining the alternate uses of lignin, including reapplying it as a soil conditioner.

5. *rZymomonas* improvements are being developed for corn fiber with NCGA/CRA and other industrial partners.

6. Cellulase enzyme improvements are being developed with Genencor and other industrial partners.

7. An outreach program has been created to make contact with potential stakeholders, including producer co-operatives, grower associations, state agencies, suppliers, processors, and customers.

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APPENDIX

BIOMASS COLLOQUIES 2000 ATTENDANCE LIST

R.R. Allmaras
USDA ARS
University of Minnesota

Carol Babb
Harris Group

Bill Beeler
Beeler Farms and
Central IL Fibers LLC

Kyle Berry
Purdue University

Jean-Marc Billy
JM Billy & Associates

Rod Bothast
National Center for
Agricultural Utilization Research
USDA ARS

Marion Bradford
A. E. Staley Co.

Roger Burken
Chief Ethanol:

Cindy Cambardella
National Soil Tilth Laboratory
USDA ARS

Tom Colvin
National Soil Tilth Laboratory
USDA ARS

Bill Cruickshank
Energy Technology Branch
Natural Resources Canada

Don Erbach
USDA ARS

Reed Ethington
Feed Products Manager
Minnesota Corn Processors

John Ferrell
Office of Fuels Development
U.S. DOE

David Glassner
Cargill Dow Polymers LLC

David Glenn
Glenn Brothers Farm
and Central IL Fibers LLC

Ralph Groschen
Ag Marketing & Development
Minnesota Dept of Agriculture

Dennis Harding
Iowa Farm Bureau Federation

Ann Hegnauer
Office of Fuels Development
U.S. DOE

Beth Hood
Prodigene

Michael Jackson
Agri-Pulp Consultant

Don Johnson
Grain Processing Corporation

Mike Knauf
Genencor International

Duane Kristensen
Chief Ethanol:

Fred Kuzel
Great Lakes Regional Biomass
Energy Program

Jerry Larson
MN Coalition for Ethanol

William E. Larson
Department of Soil, Water & Climate
University of Minnesota

David Lightle
National Soil Survey Center
USDA NRCS

Dale Lindquist
Agri-fibers LLC

Carl Lundell
MCP Co-Op Founder

Patrick McCroskey
Diversa

Ron Mells
Mells Industries

Steve Mercer
Double M Farms Inc and.
Kearney Area Agricultural
Producers Assn
(KAAPA)

Robert E. Meyer II
Minnesota Corn Research
& Promotion Council

Katherine Mullen
Institute for Local Self Reliance

Bruce Nuzum
Iowa Area Development Group

Don Reicosky
USDA ARS

Jeff Roseashan
Novartis

Keith Sannes
Agricultural Utilization Research
Institute State of Minnesota

Tom Schechinger
Biomass AgriProducts, LLC

Phil Shane
IL Corn Growers Assn

Jim Shepers
USDA ARS

Kevin Shinners
Department of Biological Systems Engineering
University of Wisconsin

Todd Sneller
NE Ethanol Board

Bill Snyder
Universal Pulping

Bob Sutthoff
Enzyme Development Corp

Hank Talbot
Dow/Mycogen

Jeff Tolan
Iogen
Virginia Tolbert
Oak Ridge National Laboratory

Richard M. Veazie.
Lurgi PSI

Jim Vogt
John Deere Ottumwa Works

Marie Walsh
Oak Ridge National Laboratory

Bill Weber
Case New Holland

Gary Welch
Williams Energy

Ed Wene
Agricultural Utilization Research Institute State of Minnesota

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13. ABSTRACT *(Maximum 200 words)*

A series of four colloquies held in the first quarter of 2000 examined the expected development of biomass commercialization in the next 2 to 5 years. Each colloquy included seven to ten representatives from key industries that can contribute to biomass commercialization and who are in positions to influence the future direction. They represented: Corn Growers, Biomass Suppliers, Plant Science Companies, Process Engineering Companies, Chemical Processors, Agri-pulp Suppliers, Current Ethanol Producers, Agricultural Machinery Manufacturers, and Enzyme Suppliers.
Others attending included representatives from the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory, the U.S. Department of Energy's Office of Fuels Development, the U.S. Department of Agriculture, environmental groups, grower organizations, and members of the financial and economic development community.

The informal discussions resulted in improved awareness of the current state, future possibilities, and actions that can accelerate commercialization. Biomass commercialization on a large scale has four common issues: 1) Feedstock availability from growers; 2) Large-scale collection and storage; 3) An economic process; 4) Market demand for the products.

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