Feedstock Roadmap Colloquies Report

Feedstock Harvesting and Supply Logistics Research and Development Roadmap

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EXECUTIVE SUMMARY

Critical issues for supplying biomass feedstocks over the next 3 to 10 years were discussed in seven colloquies held between March and May 2003. The purpose of the sessions was to accelerate the commercialization of corn stover and cereal straw feedstocks for conversion to low cost fermentation sugars for the production of fuels, chemicals and materials.

The results of the colloquies will provide information for the development of a FEEDSTOCK ROADMAP that is responsive to customers' needs while addressing stakeholders concerns. The feedstock needs were segmented into five categories:

- Harvesting
- Collection
- Transportation
- Storage
- Preprocessing

Stakeholders were mostly concerned about sustainability and economic viability.

The colloquies included six to twelve participants, stakeholders in a position to influence the future of the industry. Participants generally had a broad knowledge of the issues, with in-depth expertise in one or more of the key areas. They represented the following segments:

- Corn and Wheat Growers
- Ag Equipment Manufacturers
- Potential Biomass Processors
- Environmental NGOs
- Farm Group NGOs
- States/communities
- USDA/Univ/National labs
- Biomass Processors

A biorefinery typically requires 1 million dry tons (dt) annually to be economic. Smaller plants may become more economical with additional development. The target delivered feedstock price is $30/dt, with a net return of $20/acre (ac) or more to the farmer. The target appears achievable with one pass harvest and bulk delivery of clean feedstock. The analysis is complex, and a systems approach is required.

Harvesting

Corn stover and straw make up more than 60% of existing residues. They are available now and similar in composition to energy crops like prairie grass, a feedstock expected to be available after the technology is proven. Conversion of these residues to fuel ethanol requires just 14% to 22% of the energy for petroleum refining of gasoline.

There are significant regional differences and differences in harvesting stover and straw. More corn stover is produced than straw, but straw is more readily removed in areas where moisture retention in the soil is not a concern. Straw collection infrastructure is generally well developed, while corn stover collection is not. When cereal grain is ready to harvest, straw is usually 20% moisture or less, suitable for baling. In contrast, stover is 50% moisture and must remain in the field to dry and be collected later, depending on the weather. A wet harvest season can prevent its collection entirely.

The availability of excess stover and straw for harvesting after erosion requirements are met is dependent on cropping practice and the economic and environmental benefits. Tillage practice greatly affects availability. No-tillage results in most of the surface available for removal, especially when cover crops are employed. In contrast, no excess is available with conventional tillage, when less than 30% of the surface is covered. Since less than 20% of farmers no-till and more than 60% conventional till, a major shift in practice is needed for sustainable removal.

Collection

Traditional baling methods add cost, \$15/dt, and no value. One pass harvest can lower the delivered cost to less than \$20/dt within a 15 to 20 mile radius. While producers are still developing their conversion process, most have decided a clean bulk product is best, reducing the plant investment the equivalent of an additional \$5/dt or more. Feedstock can be wet or dry, and the composition will determine its value. One pass harvest also reduces the risk of corn stover harvest IF storage of wet harvested material is resolved.

A version of one-pass harvest

Prototypes for one pass harvest of straw and stover are under development, adapting existing equipment. There are many variations possible, and until a better market definition is available, a new design will be limited to paper studies.

Transportation

Due to the bulky nature, the cost of transportation is 20% to 40% of the cost within a 50 mile radius. While bulk density can be increased, the cost of densification generally offsets any savings. As a result, local biomass sourcing for biorefineries is expected, providing farmers ample opportunity to participate in the value chain.

Load and Go Wagon

Transportation from the field to a storage site following harvest needs to be kept short if truck requirements are to remain manageable. Collection within a 50 mile radius for one site requires about 5 times the trucks and wagons compared to a 15 mile radius. Short line rail delivery from 3 or more collection sites to supply the plant appears most advantageous compared to trucking.

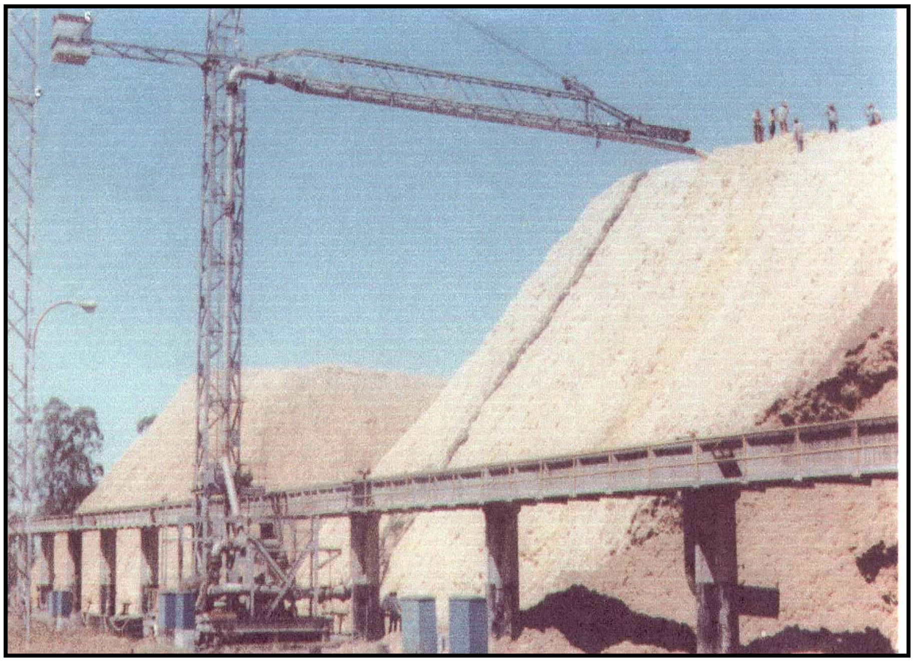
Storage

Maintaining quality of feedstock in storage led the list of participant's concerns. Easy access to transportation is required.

All were familiar with dry storage, mostly bales, and the associated needs to stay below 20% moisture, keep dry and protect from fire. Pest infestations have not been noted with corn stover, but some reported straw was susceptible.

Wet storage was less familiar, considered more conducive for corn stover. Silage, fermented forage crops, typically green sorghum and corn plants has been practiced for years as a way to preserve feedstock for ruminant animals. These crops are chopped and stored in bags, bunkers or silos at 65% moisture. The storage life can extend to years, with losses less than 3%.

Some are looking at adapting bagasse type storage, large 250,000 dt piles built via circulating liquor that conveys the feedstock from wagons or trailers from the field after it is washed and milled to a particle size that insures good compaction and preservation in storage. Less area is required; fire is eliminated when stored above 65% moisture. The material processes easier as 80% of the solubles are removed in storage. Water management and other issues remain. Validation of this method is required for other crops like stover and straw.



Wet Bagasse Storage

Preprocessing

Most processors want a clean liquid, fermentable sugars, delivered to the processing plant. Short of this, clean feedstock that has not touched the ground, unspoiled, is desired. Consistency is important. Most of these can be accomplished during collection and storage operations.

Drying and densification is desired if costs are offset by benefits, and few expect this will be the case. Using all or part of the storage time for chemical, biochemical or microbial treatment offers potential. While this processing probably is under different regulatory requirements than storage, it may be segregated and controlled separately.

Conclusions

- Feedstock is a major cost component and offers many areas for cost improvement before it enters the plant. Meeting the target price and net income is likely, especially in areas with high yields and much excess residue.

- Sourcing the feedstock quantity—1 million dt—has a high risk. The scale of collection is 4 to 10 times larger than previous experience. Baling is a higher cost, but is more certain than bulk collection, especially for straw, until one pass harvest and wet storage for stover becomes a reality.

- Farmers are the key determinate, and a shift in tillage practice is needed to collect straw and stover if quantities and costs targets are met. They are expected to participate more in the value chain since the stover and straw is inherently local. Partnering with the processor insures a win-win for both.

- The interdependence of supply and processing requires a systems approach for feedstock sourcing.

- Short term, two to three years
    - Dry feedstock is most likely to be chosen to supply biorefineries.
    - Straw collection will be favored due to reduced supply risk compared to stover

- Mid Term, four to seven years
    - The economic and environmental advantages of one pass harvest and wet storage will be validated
    - Chemical, biochemical and microbial treatments will emerge, supplying a portion feedstock as a liquid
    - Industry will begin to move more rapidly towards sustainable production as global climate change policies emerge and add incentives—social, environmental and economic

- Long term, 2014 and beyond,
    - Other feedstocks—especially energy crops grown on marginal croplands--will emerge as the processing technology is proven
    - Plant science will enhance the feedstock value
    - Co-products from the biorefinery will become more significant in their economic impact on the product mix.

Recommendations

1. **Focus on high potential areas:** In the US there are a limited number of sites that can initially supply feedstock in the quantities required in the short term. Addressing their needs helps insure the US sites are considered along with those in Canada and Europe.

2. **Removal impact:** Evaluating the impact on the crop system as practiced by growers in high potential areas, including the soil, quantity and components removed, crop rotation, other environment and economic factors is needed.

3. **Prototype Collection:** A number of one pass prototypes are under development. Continuing the development and applying these in high potential areas will insure they meet the customer requirements in these regions.

4. **Multiple Storage Scenarios:** Variations of dry bulk storage and wet storage studies are required to validate the process for local crops and conditions

5. **Systems Approach and Life Cycle Analysis:** "Everything is connected" is apt here, and the supply chain needs to be addressed. Since different proprietary processes are employed, some flexibility will be required in the analysis

6. **Preprocessing:** Use a portion of the extended storage time between harvest and processing to move towards supplying a feedstock that flows from a pipe in lieu of solids from a field.

Introduction

Critical issues for supplying biomass feedstocks over the next 3 to 10 years were discussed in seven colloquies held between March and May 2003. The purpose of the sessions was to accelerate the commercialization of corn stover and cereal straw feedstocks for conversion to low cost fermentation sugars for the production of fuels, chemicals and materials. The results of the colloquies will provide information for the development of a FEEDSTOCK ROADMAP that is responsive to customers' needs while addressing stakeholders concerns.

1.1. Colloquy Organization

An initial colloquy was organized for customers in the near term to define their feedstock needs. Based on their advice, an additional six colloquies were organized that addressed these needs and related issues.

Companies with near term plans to use stover and straw for feedstock and grower-members from the National Corn Growers Association (NCGA) and the National Association of Wheat Growers (NAWG) were included in the initial colloquy to define feedstock supply needs. The companies— Abengoa, Cargill-Dow LLC and DuPont—are cost-sharing in funds received from the DOE for use of stover and straw feedstocks for production of fermentation sugars for conversion to fuels, chemicals and materials.

The feedstock needs were segmented into five categories:

- Harvesting
- Collection
- Transportation
- Storage
- Preprocessing

These segments were further developed in the next six colloquies located in regions of "high feedstock availability," but with different climate, crops and infrastructure: Illinois, Minnesota, Oklahoma and Idaho. The colloquies included six to twelve participants, stakeholders in a position to influence the future of the industry. They represented the following segments:

- Corn and Wheat Growers
- Ag Equipment Manufacturers
- Potential Biomass Processors
- Environmental NGOs
- Farm Group NGOs
- States/communities
- USDA/Univ/National labs
- Biomass Processors

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

A listing of attendees is in Appendix A.

Each colloquy began by stating the purpose of the colloquy and a “Big Picture” discussion of the overall feedstock harvesting and logistics problem. A few points for each segment—harvesting, collecting, storage, transportation and pretreatment—were listed as an introduction for that segment. An open, informal discussion ensued, beginning with the processor and producer’s perspective and working through the supply chain.

Colloquies were facilitated by James Hettenhaus. William West co-facilitated and served as the record keeper of the meetings. The facilitator guided discussion to ensure each participant shared in the development and that others in the audience helped clarify and develop topics. The co-facilitator recorded discussions as they were occurring, using computer-assisted facilitation tools. In addition, he identified research needs from the discussion and copied each into the research category.

Participants had access to individual computers linked together, displaying the information captured by the recorder. Participants could enter comments under the captured topics too. Information entered by the recorder and the participants appeared simultaneously on everyone’s computer and were projected on a screen at the front of the room.

At the end of the discussion, participants reviewed the list of research needs copied from the discussion and added any additional research needs. Ranking or scoring issues and needs was done via the computers and the results were displayed and discussed by the participants. All the information entered—comments and ranking—was anonymous.

Each stakeholder colloquy concluded by asking the participants to express their number one “take away” (issue, potential solution, new knowledge, etc.) from the colloquy. The detailed results are included in Appendix B.

The findings will be used to help define the FEEDSTOCK ROADMAP and set research and development priorities to accelerate commercialization of stover and straw feedstocks.

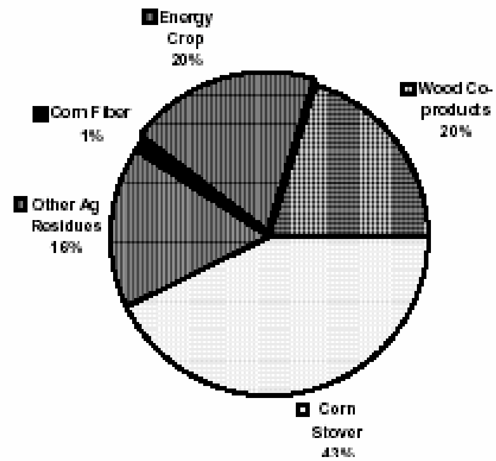
1.2. Feedstock Choice

Some questioned why Corn Stover and Straw, not something already collected, like corn fiber.

The quantity and ready availability of stover and straw make them an early choice for the initial biorefineries. For example, Table 1 shows Ag residues are nearly 60% of available biomass while corn fiber from wet milling operations represents only 1% of the total biomass available (Glassner, et. al., 1998, Corn Refiners Association, 2002).

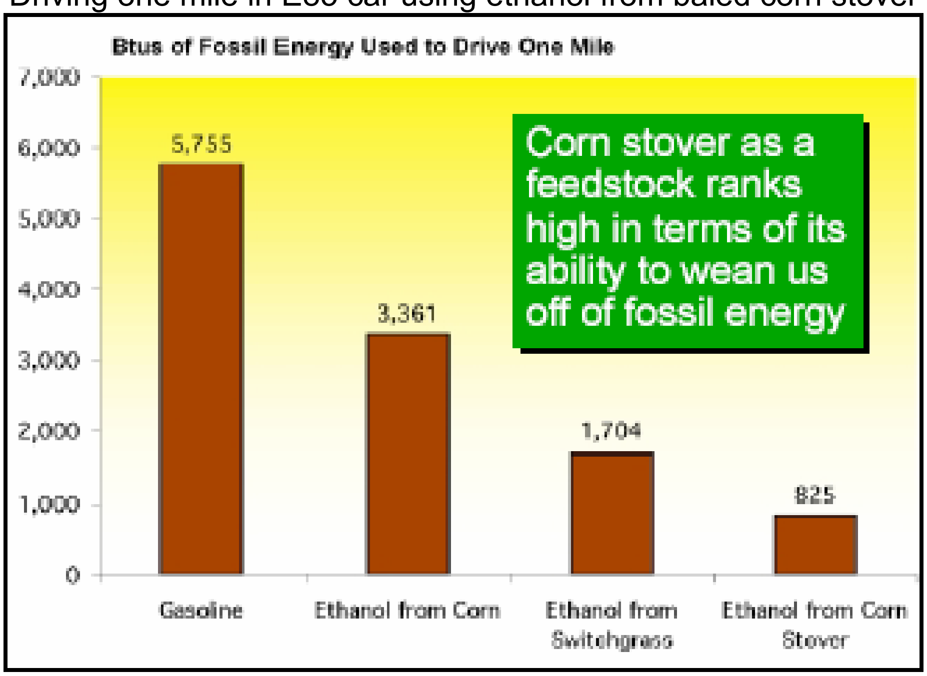
Table 1.
Biomass Available at $50/Dry Ton or Less
(Millions of Dry Tons)

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



In addition, the energy requirements for processing corn stover to E85 from corn stover using present methods has been investigated and found to be most favorable, using only 14% of the fossil energy to travel one mile compared to gasoline , Figure 1 (Sheehan, et. al., 2002). Others found corn stover conversion to E85 requires 22% of the energy for gasoline refining (Edwards et. al., 1999).

Figure 1.
Energy Requirements for Fuel Ethanol I
Driving one mile in E85 car using ethanol from baled corn stover



Industry Segments

2.1. Producers

Regional differences and differences in managing stover and straw are significant. Unless irrigated, more corn stover is produced than straw, but straw is more readily removed in most areas where moisture retention in the soil is not a concern. Straw collection infrastructure is generally well developed, while corn stover collection is not. When cereal grain is ready to harvest, straw is usually 20% moisture or less, suitable for baling. In contrast, stover is 50% or more on average and must remain in the field to dry and be collected later, depending on the weather. A wet harvest season can prevent its collection entirely.

Grower participation in the value chain is more likely when the technology is proven than with grain processing plants since feedstock transportation cost is higher, limiting collection to local or regional areas.

Corn grain is a commodity, and the local price is constrained by relatively low shipping charges from distant supply points. For example, corn grain can now be moved from the Central IL to Gulf Ports for 40¢/bu, $14/dt, increasing the grain price 20%. For $14/dt stover or straw can be moved about 100 miles, and the delivered price increases 50%, making distant suppliers or customers less likely.

Benefits to the farmer from removing excess stover were questioned. Present markets are negligible. Less than 5% is used for animal bedding and feed. Some have historically rented harvested fields for grazing, charging $5 to $10/ac. This practice is declining as combines have become more efficient, lodging is less with Bt corn and cattle ranching has grown more "factory-like".

Sustainable removal is required. Surface cover is needed to prevent wind and water erosion. Removal depends on local factors. In some dry areas surface cover is required to retain moisture, mostly in western areas of the grain belt. Further east, surface cover is given as a major reason for tilling, as the cover prevents the cold, wet soils from warming in the spring, delaying planting and reducing yield.

<u>Environmental benefits</u> accrue by reducing the need to till for residue management, less N fertilizer to prevent denitrification in the next crop and the net fossil fuel offset accrued when the feedstock is processed.

- *Reduced tillage: Plowing the residue under oxidizes the Soil Organic Material (SOM) to CO_2 as the anaerobic soil is exposed to air. The more disruptive the tillage, the greater is the loss. A deficit in SOM can actually occur (Reicosky et. al., 1998). If the residue is left on the surface, more than 80% of the surface material is lost as CO_2 while about 40% of the roots add to SOM (Cambardella et. al., 1999).*

- *Less N fertilizer: Nitrogen leaching and NOx emissions may decline if the residue is removed and not plowed under, depending on the crop rotation and N fertilizer required to prevent denitrification of the next crop.*

- *Fossil fuel offset: Engineering studies show a net reduction in 170 kg C Equiv/ ton of stover (Levelton et. al., 2000).*

Economic benefits from selling the excess stover are estimated to be $10 to $40/ac net income depending on the yield, tillage practice, nutrient value and local conditions. Carbon credits may eventually add to this economic value.

- *Selling excess stover or straw priced at $30/dt may net the farmer more than $10/ acre if baled and more than $20/ac with one pass harvest and rail transport (Atchison et. al., 2003, Shinners et. al., 2003) Tables 2 and 3.*

Table 2
Excess Stover or Straw Sale
Net to Farmer, $/ac
W/Custom Bale & Haul

Basis: $30/dry ton delivered, one 30 mi radius collection site, 1.5 M ac			
1 dt/ac left in field	*130 bu/ac*	*170 bu/ac*	*200 bu/ac*
1:1 ratio, 15% moisture, sell	*2 dt/ac*	*3 dt/ac*	*3.8 dt/ac*
Sale, $30/dt	*60.00*	*90.00*	*114.00*
P & K Nutrient credit ($3.20/dry ton)	*$ (6.40)*	*$ (9.60)*	*$ (12.16)*
Reduced Field Operations	*10.00*	*10.00*	*10.00*
Total Revenue Increase	*$ 63.60*	*$ 90.40*	*$ 111.84*
Less Custom Bale, $14.60/dt	*(29.20)*	*(43.80)*	*(55.48)*
Hauling, 30 mile radius, $9/dt	*(18.00)*	*(27.00)*	*(34.20)*
Net to farmer	*$ 16*	*$ 20*	*$ 22*

Wheat infrastructure is well developed for baling, corn stover baling infrastructure is not. Baling corn stover is inherently more risky, since an indefinite period is required to field dry the material after the grain is harvested.

One pass harvest offers more opportunity to lower cost and reduce harvest risk. Prototypes are currently under development, and further discussed in Section 3.2. Collection.

Table 3 *Excess Stover or Straw Sale* *Net to Farmer, $/ac* *W/One-pass Harvest & Rail*			
Basis: $30/dry ton delivered, 3-15 mi radius collection sites, 1.5 M ac			
1 dt/ac left in field	*130 bu/ac*	*170 bu/ac*	*200 bu/ac*
1:1 ratio, 15% moisture, sell	*2 dt/ac*	*3 dt/ac*	*3.8 dt/ac*
Sale, $30/dt	*60.00*	*90.00*	*114.00*
P & K Nutrients ($3.20/dry ton)	*$ (6.40)*	*$ (9.60)*	*$ (12.16)*
Reduced Field Operations	*10.00*	*10.00*	*10.00*
Total Revenue increase	*$ 63.60*	*$ 90.40*	*$ 111.84*
Less One-pass Harvest	*(16.29)*	*(16.29)*	*(16.29)*
Field to Collection site transport	*(10.20)*	*(15.30)*	*(19.38)*
Rail from collection site, $7.50/dt	*(15.00)*	*(22.50)*	*(28.50)*
Net to farmer	*$22*	*$ 36*	*$ 47*

The National Renewable and Energy Laboratory uses $30/dt delivered cost to the biorefinery for the base case (Aden et. al., 2002). The Phosphorous and Potassium content in straw and stover is typically 0.1% and 1% respectively, valued at $3.20/dt (Glassner et. al., 1998).The N fertilizer value is more complex, and depends on crop rotation and local conditions. Reduced field operations are estimated to reduce inputs $10/ac for preparation of the seed bed.

- *Carbon credits are likely to add additional economic incentive in the mid- to long-term. In the European Union, carbon is currently trading for about $35/mt C equiv, offering potential value as GHG offset markets emerge. There are at least three ways to reduce inputs and improve carbon credits: adding soil carbon*

    1) *Reducing tillage or no-till sequesters about 0.5 metric tons C equiv/ha (0.2 mt/ac). The increased soil carbon improves yields, and this benefit continues with each crop year. Eventually, over decades, soil carbon equilibrium is achieved.*

    2) *Reducing N fertilizer use, depending on crop rotation offsets 0.17 to 3.5 tons of N_2O/100 tons applied (CAST, 1992). Microbes desire a 10/1 ratio of C/N for breaking down residue. Since the C/N ratio of straw and stover is 40 to 70/1, 1% N fertilizer is typically recommended to avoid denitrification of the next crop. For 1,000 acres of 170 bu/ac corn, 30 to 40 tons of N fertilizer may be avoided, the equivalent of 2 to 43 mt C equiv/ac.*

3) *Converting feedstock to fuels, chemicals and materials, offsetting fossil feedstocks. E85 reduces GHG 64% compared to gasoline The effective benefit per dry ton biomass feedstock processed was 170 kg C equiv mitigated per dt corn stover for 25 MPG and 80 gal/dt corn stover.*

2.2. Processors

Low cost fermentation sugars offer the chemical industry a potentially economic and sustainable feedstock for production of fuels, chemicals and materials. In previous colloquies (Hettenhaus, 2000, Ashworth et. al., 2002), sourcing these sugars is attractive when they approach 4¢ per pound. BUT most want fermentation sugars, not bulky solids from the field.

Sustainable supply is of prime importance to the processors. Assurance of sustainable removal is required. Some processors are willing to compensate the grower for any extra effort required for harvesting grain now in a more sustainable manner, and are willing to extend this policy to stover and straw feedstocks. In the colloquies, most are just beginning to consider the details for achieving a sustainable supply. These include the following:

<u>Stover and Straw</u> are both acceptable for the same process. They will not be mixed, but can be run separately with minor adjustments. Multiple feedstocks may reduce harvest risk and increase Ag machinery utilization, reducing fixed cost of collection, transportation from the field and storage.

In addition, prairie grass and soybean stubble can be similarly processed. The latter may be removed if a cover crop is grown that provides soil erosion protection. As the feedstock market develops, prairie grass may replace wheat in areas with marginal yields of 40 to 50 bu/ac—too low to be viable for collection after erosion needs are met.

<u>Quantity</u> required is about 1 million dt annually. A reliable supply with off-site storage and Just-In-Time delivery is the pro-forma model for most.

The feedstock quantity, equivalent to 80 million gallons of ethanol, is relatively small, about 10% the size of petroleum refineries. Valero, a major oil refiner, operates plants equivalent to 12 million dt feedstock/year. with average daily capacities of 100,000 barrels/day (4.2 million gallons/day).

<u>Availability</u> of excess straw is better now than stover for several reasons. Infrastructure for baling straw is widely available. Stover is hindered by lack of stover baling experience and uncertainty of drying time in the field—dependent on the weather.

Quality of feedstock must be clean. It can be dry or wet, but not spoiled. Consistent feedstock composition and properties are desired, but more information remains to be developed.

The stover and straw is stable below 20% moisture and above 65% moisture when stored properly. In between these values, the material is most susceptible to decomposition.

Feedstock Pricing has a major effect. Pricing based on sugar composition and ease of processing is expected by some to emerge. Baling adds cost, about $15/dt, no value.

A $5/dt change in feedstock price impacts ethanol 5¢ to 7¢/gallon for 80 gal to 100 gal/dt yield. Rapid analytical methods for compositional analysis are under development now. Methods are expected to be validated and available for incorporating in a feedstock payment program (Hames et. al., 2002).

Business Models generally assume a biomass supplier(s) will be an intermediary in the supply chain: contract harvesters working with a Co-Op, LLC or other entity mostly composed of farmers who are the growing and supplying the feedstock. Some Technology Developers would give preferential licensing of the process technology to growers and/or welcome them to participate in the value chain.

Some issues that require further consideration include the following:

- Buy the field: with one pass harvest, it may be more efficient to combine crops instead of maintaining identity.

  Growers in an earlier forum asked if the field could be planted too as part of the agreement, not entirely in jest (National No-till Conference, 2003).

- Covering collection "out of pocket cost:" The operating cost for baling is $8 to $10/dt. Transport cost is additional. How do these out of pocket costs get reimbursed, and when?

  The stover and straw is not fungible. Some early payment is likely needed from the processor or an intermediary to cover direct collection costs and better insure supply.

- Collection equipment is required. How will this equipment be purchased? Most believed it was unlikely individual farmers would make the investment. Contract operators and grower organizations were thought to meet this need.

Some suppliers, Koch owned Diversified Environmental (Hettenhaus and Schechinger, 1999) and Dow BioProducts, Ltd., formerly Isoboard, purchased balers. The balers are used by their employees or contract operators to bale and remove the straw and stover from the fields (Karolat, 2003). In both cases, the quantities are relatively small, a maximum of 150,000 dt annually.

2.3. Ag Equipment Manufacturers

Representatives from both large and small Ag Equipment Manufacturers, Universities, National Laboratories, Contract Balers and others in a position to effect the development of improved equipment for harvesting and collecting feedstock participated. The key issue resolved around one question: "What does customer want?" For example:

- One-pass harvest?
  Cereal Grains with stripper header or conventional header?
  Corn with ear and stalk? Or grain and stover?

- Pre-Processing
  Component separation? Which parts? How disposed?
  Size Reduction? How much?
  Where? In field or at collection site?

- On-farm storage or at a collection site?

Local requirements will vary. In areas where soybeans and corn rotate, the needs are different from wheat and corn or wheat and cotton rotation. For wheat, stripper headers work well now, leaving a standing stalk that is clean and readily harvested.

Existing equipment may be adapted, and several modifications have been demonstrated (PAMI, 1998; Quick et. al., 2002; St. George, 2002).

Development cost for a new design is said to be $2 million or more for prototypes, with millions more to follow. The uncertainty of the customer's needs, regional differences, market size uncertainty and the generally low economic performance of this industry segment makes any up-front development highly unlikely beyond paper studies.

2.4. Transportation Companies

Transportation is 20% to 40% of the feedstock cost within a 50 mile radius, $6 to $12/dt. In addition, the traffic required to transport million ton quantities during the harvest and throughout the year makes logistics a significant concern. The limits of truck transport for bales are well-documented (Turhollow, et. al., 1996).

Pipelines require years to construct with high capital requirements. Rail infrastructure exists and Short Line and Main Line transport was discussed.

Short lines service a local or regional area, typically moving single or several cars between shipping and receiving points to and from the Main Lines. Their working rules are more flexible and their cost structure is inherently lower, with less overhead. Short line traffic is seasonal, peaking during spring planting and fall harvest. Moving 40 to 60 units per day of feedstock is a significant opportunity as they typically average 60 to 150 car moves per day.

Rail transport from collection centers to the processing site can offer logistical and cost advantages, especially where short-line rail is available: Table 4.

Table 4
Plant Feedstock Requirements
Rail and Truck Traffic Volume, units/day

Plant, dt (000)		*700*	*1,000*	*2,000*	*4,000*	*6,000*
Mode	*Moisture*	*Units/day(60 hr/week delivery)*				
Rail Cars	*50 to 70%*	*44*	*64*	*130*	*250*	*380*
Trucks	*50%*	*67 (200)*	*95 (280)*	*190 (570)*	*380*	*570*
Trucks	*70%*	*111 (333)*	*160 (480)*	*320 (1000)*	*640*	*1,000*
Trucks	*Bales[1]*	*41 (123)*	*60 (180)*	*120 (360)*	*240*	*360*

[1]Bales are based on 20 tons/load, 15% moisture

Short-lines may lower transport cost to $6/dt or less for distances up to 200 miles, especially when combined with smaller collection radius, less than 5 miles (Atchison et. al., 2003).

Main line carriers, such as BNSF and Union Pacific, are more restrictive with work practices and focus on moving cargo long distances. As a result, their present interest with biomass is limited to delivering the final products, fuel ethanol, chemicals and materials to their destination.

2. 5. Other Stakeholders

Input from other stakeholders indirectly involved was solicited. This included Public R&D organizations, universities, educators, traditional agriculture industry sectors, environmental advocacy groups, states and rural communities. Their primary concern was environmental sustainability and economic viability.

Feedstock Removal, Storage & Transportation

Participants reflected a wide spectrum of opinions, impressions and value judgments on the environmental effect of removal, the stover value, removal methods, storage and transport need. In addition, clear differences exist between handling corn stover and straw. The amount of feedstock available will clearly be subject to mostly local conditions and attitudes.

3.1. Harvesting

The areas where the colloquies were conducted generally contain adequate excess residue to economically supply biorefineries with large feedstock quantities. The grower practice and attitudes ultimately determine availability.

Availability *is greatly affected by tillage practice, since tillage increases the amount of residue that must remain for soil erosion control. For example, Table 5 shows the variation in required erosion cover for selected counties (Nelson, 2001). Mulch till can significantly reduce the amount available in some areas: Peoria County, IL, Jasper County, IA, Rock County NE and Harper County, OK. If conventional till, i.e., less than 30% of the surface is covered, no removal is permitted based on the Revised Universal Loss Equation (RUSLE) and the Wind Erosion Equation (WEQ), the USDA models upon which the report is based.*

Table 5
County-Level Stover and Straw Cover Required for Water and Wind Erosion

		Corn, BU/ac		***Wheat, BU/ac***	
State	***County***	***No-till***	***Mulch till***	***No-till***	***Mulch till***
IL	*McLean*	*20*	*41*		
IL	*Peoria*	*39*	*87*		
Iowa	*Grundy*	*30*	*50*		
Iowa	*Jasper*	*52*	*126*		
NE	*Rock*	*45*	*75*	*20*	*40*
NE	*Dawson*	*30*	*45*	*20*	*30*
OK	*Harper*			*20*	*60*
OK	*Washita*			*20*	*40*

For ANY plant to be supplied with stover or straw feedstock, a major shift in area tillage practices is likely required to comply with erosion requirements. Less than 20% of the Corn is no-tilled, and the 63% that is conventionally tilled is not available, Table 6 (Conservation Technology Information Center Survey).

Table 6 *Corn Tillage Practice* *% Total Acres for Grain*				
Year	***1994***	***1996***	***1998***	***2000***
No till	*18*	*17*	*16*	*18*
Mulch	*22*	*23*	*23*	*19*
Conventional	*60*	*60*	*61*	*63*

For wheat, less than 10% of the acres are no-till. Unless wheat is irrigated, much of the wheat yield on dryland is below 40 bu/ac, negating any straw removal except on no-till fields, Table 7.

Table 7 *Wheat Tillage Practice* *% Total Acres for Grain*				
Year	***1994***	***1996***	***1998***	***2000***
No till	*5*	*7*	*9*	*10*
Mulch	*25*	*24*	*23*	*20*
Conventional	*69*	*69*	*68*	*70*

Harvest differences between corn and cereal grains result in different approaches.

Cereal straws are dry when the grain is harvested. The chaff can be handled separately (St. George, 2002) and other wheat straw components can be selectively harvested (Thompson, et. al., 2002).

Corn stover is too wet for dry storage when the grain is harvested (Myers et. al., 1992). There are more components, therefore more choices for separation, i.e. ear and stalk, grain-stalk-cob, remove leaves and husk, or just leaves.

Research Areas identified included the following areas:

- Identify "high potential" areas for feedstock removal to examine environmental and economic impact: since surface residue excess depends on local conditions, allocate resources to study sites that are most likely for initial biorefineries.

- Component economic and environmental value: erosion control and soil organic material may be impacted by component differences. Cobs offer commercial value, for example, as a carrier for herbicides and other chemicals, cat litter and metal polishing applications. Leaves may offer good surface cover, but only in certain conditions like narrow rows and hybrids with high crowns.

- More and varied crop rotations that improve economic and environmental return with biomass sale: for example, inclusion of cover crops can reduce the need for stover and straw cover.

- No-till and drill seeding obstacles: the survey results indicate more outreach is likely needed here.

- Screen plant hybrids for sugar yield and biomass quantity: Plant science companies have pursued this strategy for corn grain processed in dry mill plants with considerable success.

3.2. Collection

For collection, farmers generally preferred one pass harvest due to less compaction and fewer field operations IF excess stover were sold and projected net incomes realized. How this can be achieved with Ag equipment remains open to many variations. To meet a cost target of $30/dt with adequate net income for the farmer will likely exclude baling.

The corn stover baling studies have largely identified the difficulties encountered with dirt, weather, collection quantity, broken bales, fire, among others (Columbus et. al. 2000; Billy, 2000; Hettenhaus and Schechinger, 2000; Montross et. al.., 2002; Pordesimo et. al., 2002). Most processors stated they preferred bulk delivery, not bales.

Bale handling at the plant adds another $5/dt or more for processing compared to bulk feedstock (Harris, 2000). One pass systems have been compared with multi-pass alternatives for wheat (PAMI, 1998) and stover (Quick et. al., 2002; Atchison et. al., 2003; Shiners et. al., 2003). Results indicate one pass harvest can deliver $30/dt target price with $20/ac or more margin to the farmer when the following conditions are met:

- *175 bu/ac or more yield*
- *75% or more removal of residue*
- *30 mile or less collection radius*
- *Bulk delivery of chopped material*
- *Collection equipment utilization is spread over 2.400 or more acres*

Revised management practices are required. Two to five times more material is removed from the field, requiring more resources. To absorb the higher fixed cost, collection equipment utilization of 2,000 acres is the minimum to achieve the cost targets.

High utilization is required to lower collection cost. Table 8 summarizes the harvest cost as a function of harvester utilization and yield (Schnitkey, 2000). For large operators, harvesting 2,400 acres during 33-16 hour days, the cost is $1.92/dt for 200 bu/ac and $1.94/dt for 170 bu/ac--a significant drop from $14.60/dt baling cost.

Table 8
Harvest Cost for Forage Harvester

Harvest Cost, $/ac				Harvest Cost, $/dt @ 75% eff		Operating Days, 16 h/day
Acres	Fixed Cost	Direct Cost	Total Cost	170 bu/ac	200 bu/ac	
900	$18.65	$ 9.30	$ 27.95	$3.88	$3.30	13
1,200	$13.99	$ 9.30	$ 23.29	$3.24	$2.75	17
1,800	$ 9.33	$ 9.30	$ 18.63	$2.59	$2.20	25
2,400	$ 6.99	$ 9.30	$ 16.29	$2.27	$1.92	33
3,600	$ 4.66	$ 9.30	$ 13.96	$1.94	$1.65	50

The costs are based on forage harvester operation. It may be more expensive than needed for lignocellulosic feedstock. The knives now employed to reduce the plant to silage cut the plant into 0.35" (90 mm) pieces for storage and later animal consumption. Just cutting the stalk to 1' (300mm) pieces in the field reduces the power needed in the field equipment, especially if the leaves and husks are left in the field, uncut.

Research Areas

- Efficient collection equipment:
  - Is component separation and size reduction best done in the field, the collection center or in the plant? What is the degree of separation and size reduction if carried out?
  - Degree of versatility?

- Sensors to determine the following:
  - Material quantity, value and quality during collection serve as the base line for downstream comparison.
  - Change in soil parameters for determining impact of removal and

- Develop a Decision Support and Control systems for “selective residue collection” and assist in determining future actions: fertilizer addition, hybrid selection, row spacing, and removal amount among others.

3.3. Transportation

Transportation was divided into two components: the harvest period when the annual feedstock supply must be removed from the field in a short time of 30 to 45 days, and the daily supply requirements of 2,000 to 3,000 dt/day for the plant. Generally, a 50 mile radius has been considered the minimum area for supplying 1 million dt. *In areas with high yields, a 30 mile collection radius can be adequate (1.8 million acres, 30% participation for 0.5 million acres, removing 3 dt/ac).* During harvest, existing resources are stretched just to bring in the grain. Increasing the resources to accommodate 3 times that quantity was seen by all as a serious stretch.

Sugar Cane harvest comes close to matching the logistics, with deliveries to one mill site reaching 24,000 dt/day, about 1,000 truck deliveries. For a 20 hour delivery day, 100 trucks per hour rumble past, in and out of the plant.

During harvest, leaving the harvested material at the edge of the field or at smaller, multiple collection sites 15 to 20 miles in diameter was suggested as ways to reduce the trucking requirements, potentially lower cost and reduce congestion.

For a 50 mile collection radius, travel distance “as the crow flies” averages 70 miles per round trip to reach a single collection site, likely requiring 2 hours to deliver a load and return.

Delivering the daily plant requirements, 2,000 to 3,000 dt/day, presented a lesser concern. Still, some reported truck congestion at ethanol plant sites delivering corn. Short-line Rail offers the possibility to reduce congestion and lower cost, transporting feedstock from the collection centers to the processing plant.

Cost can range from 20% to 50% or more of the feedstock cost depending on the distance, mode of transport and physical properties.

Research areas

- Easily applied logistic models that can plan and manage harvest transportation requirements for economic and efficient harvest

  For bulk collection, wet or dry, maintaining combine productivity requires wagons to be continuously available for off-loading collected material for transport to collection site. Applying tools like GPS and logistical algorithms *for real time harvest helps insure resources are best deployed to meet demand.*

- Economic and effective transport of material under a variety of conditions is needed—an integrated system analysis that addresses material handling properties, bulk density and shelf life in transport

  Investigate bulk density, particle size and moisture affect on material handling characteristics
  - *For dry material, particle size reduction and pelletizing may be viable for some situations*
  - *Wet material moisture and bulk density can be changed by dewatering at the collection site*
  - *Vibration of the container increases bulk density for dry and wet materials when is vibrated, but unloading can be difficult*

  Pipelines have been suggested in several venues (Hettenhaus, et. al., 2000; Schechinger, 1999). While the cost appears prohibitive in some situations, further scenario analysis appears warranted (Kumar et al, 2003).

  Pelletizing may also be appropriate for some situations (Sokhansanj et al, 2000, 2002).

- Reduce liability from fire when transporting material

  Dry stover and straw is readily ignited. Both have caught fire in transit. High moisture material may auto-ignite in transit. Development and promulgation of safety standards that address carrier liability issues are needed.

- Transport equipment suitability

  A wide variety of equipment is available. Using "standard" equipment better insures ready availability and low cost. Include equipment suitability as part of the integrated system analysis.

3.4. Storage

Maintaining quality of feedstock in storage led the list of participant's concerns. Easy access to transportation is required.

All were familiar with dry storage, mostly bales, and the associated needs to stay below 20% moisture, keep dry and protect from fire. Pest infestations have not been noted with corn stover, but some reported straw was more susceptible.

Wet storage was less familiar, considered more conducive for corn stover. Silage, fermented forage crops, typically green sorghum and corn plants has been practiced for years as a way to preserve feedstock for ruminant animals. These crops are chopped and stored in bags, bunkers or silos at 65% moisture. The storage life can extend to years, with losses less than 3%.

Some are looking at adapting bagasse type storage where large 250,000 dt piles are built via a circulating liquor that conveys the feedstock from wagons or trailers from the field after it is washed and milled to a particle size that insures good compaction in storage (and sugar extraction), saturating it to 80% moisture. Residual sugar results in fermentation that drops the pH below 4, halting microbial activity. Less area is required; fire is eliminated when stored above 65% moisture. Water management and other issues remain. Validation is required for other crops like stover and straw.

A comparison of dry bale and wet bulk storage is shown in Table 9 (Atchison et. al., 2003)

Table 9
Dry and Wet Storage Comparison

Parameter	Dry (bales)	Wet storage (Silage and Ritter method)
Dry Density, lbs/ft3	7 to 10	12 to 14
Storage area	10x	1x
Storage Loss	>10%	<5%
Foreign matter & soil nutrients	High	Low
Non-volatile solubles Removal	Process Residue	Storage Liquor
Weather Risk	Rain	Extreme Cold
Fire hazard	High	None
Investment	Low to High	Medium to High
Storage quantity	Small, mostly farm use	Large, bagasse for pulp

Wet storage of non-wood fibers, mostly bagasse, was first commercialized by E. A. Ritter in 1950 and has been practiced by the pulp and paper industry for more than 50 years (Atchison, 1971, 1972, 1985). Major studies on a commercial scale showed pulping the stored bagasse was superior to pulping dry bagasse and fresh, wet bagasse (Moebius, 1966; Salaber and Maza, 1971; Bruin et. al., 1974). The wet feedstock contained less solubles, required less treatment, produced higher yields and had better processing characteristics when compared to dry feedstock and fresh, wet bagasse.

In addition, wet feedstock stored for 6 months was superior to "green" bagasse, the fresh material from the current harvest in processing characteristics, with 80% less solubles and higher holocellulose composition. As a result, green bagasse is held over, for processing the following year.

Research areas

- Dry Bulk storage, size reduction

  Particle size reduction increases bulk density. What is the impact on storage parameters?

- Co-product value

  The circulating liquor is high in organic acids and nutrients. Fertilizer value approaches $3.2 million for P and K in stover or straw for a 1 million dt plant. Can these components be economically recovered?

- Validation of bagasse type storage contains a long list including the following:

  - Impact on processing economics
  - Emissions, esp odor
  - Water requirements
  - Circulating liquor management
  - Nutrient management
  - Weather

  <u>Impact on processing economics</u>: removing 80% of solubles reduces the cost by increasing throughput of holocellulose material and reducing disposition cost of 400 tons of ash per day. In addition, other process savings may be achieved due to easier separation and reduced treatment needs. What happens with corn stover and straw?

  <u>Emissions, esp odor</u>: Volatile loss has not been investigated. While technically considered a farm operation, the emissions need to be determined and organoleptic properties determined.

  <u>Water requirements</u>: The stover and saturates at 80% moisture. Storing stover collected at 50% moisture—harvested when grain is ready-- requires addition of about 700 million gallons water to saturate the material for storage (based on 1 million dt annual need). Conversely, collecting 50% moisture stover recovers about 200 million gallons of water that is lost when field drying to 20% moisture.

  <u>Circulating liquor management</u>:
  How is the liquid managed between harvest, when need is greatest, and late summer, when most has been extracted from feedstock, either at collection site or at the plant. Liquid in 1million dt feedstock approaches 1 billion gallons. Water availability and its management becomes another key site selection factor.

  <u>Nutrient management</u>: Wet storage is dependent on enough nutrients to support anaerobic fermentation in the pile. With "green" stover, ample

quantities should be available. For dry stover and straw, some addition of molasses and other nutrients may be required. This can change the regulatory requirements, in addition to being an added cost.

<u>Weather;</u> Bagasse has been stored in temperate and tropical areas. What happens in colder climes?

3.5. Preprocessing

According to the processors, the most desirable “preprocessing” delivers a liquid fermentation sugar to the processing plant. Short of this, processors want clean material, preferably feedstock that has not touched the ground. In addition, the collection and storage operations man meet some preprocessing needs as they emerge:

- Collection
    - Remove standing stalks—little dirt
    - Separate components—chaff from straw, cob from husk and stalk
    - Reduce particle size—cut to desired size
    - Increase bulk density—bale, compress, pelletize

- Wet Storage
    - Clean and reduce particle size during transfer to storage
    - Remove soluble and volatile components during storage

<u>Drying is desirable</u>, especially for corn stover. When the grain is harvested, the stover averages about 50% moisture.

A patent for using the heat from microbial fermentation to dry bagasse bales from 50% to less than 20% moisture was issued more than 70 years ago (Munroe and Lathrop, 1933). The bales were sized and stacked to dissipate heat and acid fumes without fiber damage. Sheltered from the weather, bales kept for several years without serious deterioration or fiber loss. The method is described in several papers (Lathrop and Munroe, 1934; Hay and Lathrop, 1941).

This dry storage method was used for more than 40 years. However, a change to wet storage occurred in the 1960's due to increasing recognition of its disadvantages, including the following:

- *The bales were relatively small, weighing 250 lbs (115 kg) ‘as is’*
- *Mechanical handling was slow and costly*
- *The bales had to be precisely stacked to vent fumes and dissipate heat*
- *Procedures were labor intensive*
- *Several months were required to dry bales from 50 to 20% moisture*
- *Fire loss and increasing fire insurance costs*

While some progress in handling has occurred, recent experience in baling, storing and transporting has demonstrated the issues above are still valid today.

Additional treatment during storage is desirable. The feedstock is stored on average for months. All or some portion of this time may be used for chemical, biochemical and microbial treatment. If so, the process may fall under additional regulatory requirements. The benefits from value added activities can be a win-win for the biomass supplier and the processor, increasing the linkage.

An integrated approach is required, likely coupled with regional needs and processor requirements. Since the process for converting the feedstock is still under development—and there is wide variation in these processes—no universal standard is likely, i.e. No. 2 yellow dent corn with penalties for damage, moisture and foreign matter.

Research areas

In addition to collection and wet storage needs listed earlier, the addition of an interim processing step adjacent to the storage site to reduce the volume and increase the value of feedstocks delivered to the processing plant offers high potential. Some investigators are already pursuing (Vande Berg et al, 2003).

Conclusions

- Feedstock is a major cost component and offers many areas for cost improvement before it enters the plant. Meeting the target price and net income is likely, especially in areas with high yields and much excess residue.

- Sourcing the feedstock quantity—1 million dt—has a high risk. The scale of collection is 4 to 10 times larger than previous experience. Baling is a higher cost, but is more certain than bulk collection, especially for straw, until one pass harvest and wet storage for stover becomes a reality.

- Farmers are the key determinate, and a shift in tillage practice is needed to collect straw and stover if quantities and costs targets are met. They are expected to participate more in the value chain since the stover and straw is inherently local. Partnering with the processor insures a win-win for both.

- The interdependence of supply and processing requires a systems approach for feedstock sourcing.

- Short term, two to three years

    - Dry feedstock is most likely to be chosen to supply biorefineries.
    - Straw collection will be favored due to reduced supply risk compared to stover

- Mid Term, four to seven years

    - The economic and environmental advantages of one pass harvest and wet storage will be validated
    - Chemical, biochemical and microbial treatments will emerge, supplying a portion feedstock as a liquid
    - Industry will begin to move more rapidly towards sustainable production as global climate change policies emerge and add incentives—social, environmental and economic

- Long term, 2014 and beyond,

    - Other feedstocks—especially energy crops grown on marginal croplands--will emerge as the processing technology is proven
    - Plant science will enhance the feedstock value
    - Co-products from the biorefinery will become more significant in their economic impact on the product mix.

Recommendations

- **Focus on high potential areas:** In the US there are a limited number of sites that can initially supply feedstock in the quantities required in the short term. Addressing their needs helps insure the US sites are considered along with those in Canada and Europe.

- **Removal impact:** Evaluating the impact on the crop system as practiced by growers in high potential areas, including the soil, quantity and components removed, crop rotation, other environment and economic factors is needed.

- **Prototype Collection:** A number of one pass prototypes are under development. Continuing the development and applying these in high potential areas will insure they meet the customer requirements in these regions.

- **Multiple Storage Scenarios:** Variations of dry bulk storage and wet storage studies are required to validate the process for local crops and conditions

- **Systems Approach and Life Cycle Analysis:** “Everything is connected” is apt here, and the supply chain needs to be addressed. Since different proprietary processes are employed, some flexibility will be required in the analysis

- **Preprocessing:** Use a portion of the extended storage time between harvest and processing to move towards supplying a feedstock that flows from a pipe in lieu of solids from a field.

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REFERENCES

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton, J. Lukas, Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover, National Renewable Energy Laboratory, Progress Report NREL/TP-510-324328, June 2002.

Ashcroft, J., J. Hettenhaus, R. Wooley, Sugar Platform Colloquies, NREL Contract No. NREL/SR-510-31970, May 2002
http://www.ott.doe.gov/biofuels/pdfs/sugar_platform.pdf

Atchison, J. , Modern Methods of Purchasing, Handling, storage and Preservation of Bagasse – Major Advances in the Sixties, TAPPI Non-wood Plant Fiber Pulping Progress Report No. 2, October 1971.

Atchison, J., Review of Progress with Bagasse for Use In Industry (A review of progress in purchasing, handling, storage and preservation of bagasse) J. E. Proc. Intern. Soc. Sugar Cane Technologists 14:1202-1217 (1971) Franklin Press, Baton Rouge, LA, 1972.

Atchison, J., Rapid Growth in the Use of Bagasse as a Raw Material for Reconstituted Panelboard, Proceedings of the 19th International Particleboard/Composite Materials Symposium, Washington State University, 1985.

Atchison, J., J. Hettenhaus, Benefits of Bagasse Type Storage of Stover for Supplying Large Biomass Processing Plants, Corn Utilization and Technology, Conference 2002.

Atchison, J.E., J. Hettenhaus, Innovative Methods for Corn Stover Collecting, Handling, Storing and Transporting, National Renewable Energy Laboratory Subcontract No. ACO-1-31042-01, March 2003,
http://www.afdc.doe.gov/pdfs/7241.pdf

Bernhardt, D.R., Bulk Storage of Bagasse. The Sugar Journal, March 1968.

Billy, J., Corn stover in eastern Canada as raw material for the production of ethanol, Natural Resources Canada and Georges Lê of " Ressources naturelles Québec " 2001.

Bransby, David I., Cubing Grasses to Facilitate Co-Milling and Co-Firing with Coal BioEnergy 2002, www.bionergy2002.org.

Brujn, J., Gonin, C., McMaster, L., and Morgan, R., Wet Bulk Storage of Bagasse. Proc. Intern, Soc. of Sugar Cane Tech. (ISSCT) XV Congress: 1793-1820, 1974.

Cambardella, C and W.J. Gale, Carbon Dynamics of Surface Residue and Root Derived Carbon to Soil Organic Matter under No-Till. Soil Sci. Soc. of Amer. J., 1999.

CAST 1992. Preparing US Agriculture for global climate change. Council for Agricultural Science and Technology, Task Force Report 199.

Conservation Technology Information Center Survey, www.ctic.purdue.edu

Edwards, W., and D. O' Connor, Alternative and Future Fuels and Energy Sources for Road Vehicles, http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study1/Final_Report/Part1-4/FinalR_Dec24,1999.doc

Harris Group Inc., Process Design and Cost Estimate of Critical Equipment in the Biomass to Ethanol Process, Report No. 99-10600/13, Baled Feedstock Handling System, Revision 1w, Subcontract No. aco-9-29067-0, October 11, 2000

Hames, B., S.Thomas, A. Sluiter, C. Roth and D. Templeton, Rapid Biomass Analysis: New Tools for Compositional Analysis of Corn Stover Feedstocks and Process from Ethanol Production, 24th Biotechnology Symposium for Fuels and Chemicals, 2002.

Hay, H.R. and Lathrop, E.C. Storage of Crop Fibers and Preservation of their Properties. TAPPI Technical Association Papers, Series XXIV. P 412-418, 1941.

Hess, J.R., R.L. Hoskinson, T.D. Foust, K.L. Kenney, D.N. Thompson, P.G. Shaw and J. Steciak, Multi-Component Harvesting for Whole Crop Utilization, BioEnergy 2002, www.bionergy2002.org

Hettenhaus, J. and T. Schechinger, Corn Stover Harvest: Grower, Custom Operator and Processor Issues and Answers, Oak Ridge National Laboratory, 1999.

Hettenhaus, J, A. Wiselogel and R. Wooley, Producer Benefits from the Other Half of the Crop--Corn Stover, Corn Utilization and Technology Conference, May 2000.

Hettenhaus, J. and T. Schechinger, Improved Corn Stover Harvest & Collection Methods, 3rd Annual AgFiber Technology Showcase, Memphis, TN, October 2000

Hettenhaus, J., A. Wiselogel and R. Wooley, Biomass Commercialization Prospects in the Next 2 to 5 year, Colloquies 2000 National Renewable Energy Laboratory, NREL/ACO-9-29-039-01, October 10, 2000 http://www.afdc.doe.gov/pdfs/4809.pdf

Huisman, W., B.M. Jenkins and M.D. Summers, Cost Evaluation of Bale Storage Systems for Rice Straw, BioEnergy 2002, www.bionergy2002.org

Illinois Farm Business Management Custom Rate Guide--Machinery Cost Estimates, 2000, http://www.ace.uiuc.edu/fbfm/farmmgmt.htm

Iowa Farm Custom Rate Survey, 2002 http://www.extension.iastate.edu/Publications/FM1698.pdf

Karolat, W., Bio-Logical Futures Conference, Saskatoon, SK, June 14-16, 2003

Kumar, A., J. Cameron, P. Flynn, Pipeline Transport of Biomass, 25th symposium on Biotechnology for fuels and Chemicals, 2003.

Lacey, J.A., P.G. Shaw and D. Grant, Selective Harvest of Higher Value Wheat Straw Components, BioEnergy 2002, www.bionergy2002.org

Lathrop, E.C. and Munroe, T.B., Methods of Preserving Fiber for Pulp-Making Purposes. U.S. Patent No. 1,572,540, 1926.

Lathrop, Elbert C. and Treadway B. Munroe, Ind. Eng. Chem., 26:594-598, 1934.

Larson, W. E., C. Clapp, W. Pierre, Y. Morachan, Effects of increasing amounts of organic residues on continuous corn, Agron. J. 64, 204-208, 1972.

Levelton Engineering Ltd. and (S&T)^2 Consultants Inc., Assessment of Net Emissions of Greenhouse Gases From Ethanol-Blended Gasolines in Canada: Lignocellulosic Feedstocks, R-2000-2, January 2000

Little, A.D., Aggressive Growth in the Use of Bio-derived Energy and Products in the United States by 2010, DOE Contract No. GS-23F-8003H. 2000.

Mani, S., L. Tabil, S. Sokhansanj, W.J. Crerar and S. Panigrahi, Densification of Biomass - an Overview, BioEnergy 2002, www.bionergy2002.org

MacDonald, T., Ritter Bagasse Process, Pulp Paper Intl., 5 (10) 45-47, 1963.

MacDonald, T., Ritter Bagasse Process, Pulp and Paper Intern., September 1963.

Moebius, J., The Storage and Preservation of Bagasse in Bulk Form, Without Baling. Pulp and Paper Development in Africa and the Near East, United Nations, N.Y. Volume II, 1966.

Montross, M.D., T.S. Stombaugh, S.A. Shearer, S.G. McNeill, S. Sokhansanj, Collection and Characterization of Corn Stover in Kentucky, BioEnergy 2002, www.bionergy2002.org

Munroe, T.B. and Lathrop, E.C., Fiber Storage and Preservation, U. S. Patent No. 1,920,129. 1933.

Myers, Donald K., J. Underwood. Harvesting Corn residue, AGF-003-92 Ohio State Extension, 1992, http://ohioline.osu.edu/agf-fact/0003.html

Nelson, R., Resource Assessment, Removal Analysis, Edge-of-Field cost Analysis, and Supply Curves for Corn Stover and Wheat Straw in the Eastern and Midwestern United States, NREL Report, 2000.

PAMI, Prairie Agriculture Machinery Institute, Modeling and Comparing Whole Crop Harvest Systems, Research Up-Date 739, 1998, http://www.pami.ca/PDFs/Pami739.pdf

Perlack, R.D. and A.F. Turhollow, Assessment of Options for the Collection, Handling and Transport of Corn Stover, ORNL/TM-2002/44, www.osti.gov/bridge

Pordesimo, L.O., W.C. Edens, S. Sokhansanj, Soil Contamination in Collected Stover, BioEnergy 2002, www.bionergy2002.org

Quick, G. and T. Tuetken, Single Pass, Two Stream Corn and Stover Harvest Developments, BioEnergy 2002, www.bionergy2002.org

St. George, D.R., McLeod Harvest System, BioEnergy 2002, www.bionergy2002.org

Salaber, J. and Maza. Ritter Biological Treatment Process for Bagasse Bulk Storage. TAPPI Non-wood Plant Fiber Pulping Progress Report, No 2, October 1971.

Schechinger, T. and J. Hettenhaus, Corn Stover Harvest: Grower, Custom Operator and Processor Issues and Answers, ORNL/MMES Contract 4500008274, 1999.

Schnitkey, G., D. Latz and J. Siemens, Machine Cost Estimate: Combine Operations, U of IL Farm Business Management Handbook, April 2000 http://web.aces.uiuc.edu/fbfm/pdf%20files/Mach_combines_20001.PDF

Sheehan, J. , K. Paustian, K. Killian, J. Brenner, R. Nelson, D. Lightle, M. Walsh, J. Cushman, A. Aden, C. Riley, Is ethanol from corn stover a sustainable fuel? A Case Study in Cyber Farming. National Renewable Energy Laboratory, Golden, CO. In Press.

Shinners, K. and P. Savoie, Single pass Whole-Plant Corn Harvesting for Biomass: comparison of single and Multiple Harvest Streams, 25th Symp. for Fuels and Chemicals, 2003

Sokhansanj, S. and A. Turhollow, and R. Perlack Stochastic modeling of costs of corn stover costs delivered to an intermediate storage facility, http://bioproducts-bioenergy.gov/pdfs/bcota/abstracts/31/z328.pdf

Sokhansanj, S. and A. Turhollow, Biomass Densification - Operations and Costs, BioEnergy 2002, www.bionergy2002.org

Thompson, D.N., T.D. Foust, J.R. Hess, R.L. Hoskinson, T.P. Houghton, J.A. Lacey, P.G. Shaw, Selective harvest of higher value wheat straw components, BioEnergy 2002, www.bioenergy2002.org

Turhollow, A., M. Downing, J. Butler, The cost of silage harvest and transport systems for herbaceous crops, Proc., BIOENERGY '96, September 15-20, 1996, http://bioenergy.ornl.gov/papers/bioen96/turhllw.html

Vande Berg, B., J. Burdette, T. Osofsky, S, Mason, B. Carr., N. Duck, M. Koziel, Effective Digestion of Untreated Corn Stover by Microbial Enzymes, 25th Symposium on biotechnology for Fuels and Chemicals, 2003.

Wallace, R., Calculating the cost of corn stover through Area 100 (Feedstock Handling), NREL Technical Memo, January 9, 2003.

Walsh, M.E., et al, Biomass Feedstock Availability in the United States: 1999 State Level Analysis, Bioenergy Information Network, Bioenergy Feedstock Development Program, Oak Ridge National Laboratory, January 2000. http://bioenergy.ornl.gov/resourcedata/

Wang, S.J.I. and Tao, H.Y., Bagasse Handling and Storage System at Pingtung Pulp Factory. TAPPI Non-wood plant Fiber Pulping Progress Report no. 9, 1978.

APPENDIX

A. Attendees (to be supplied by INEEL)

B. Ranking Results, sent separately.