

# CORN STOVER CO-PRODUCTS: A COMMERCIALIZATION COURSE

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## ABSTRACT

Sugar and Paper co-products produced from corn stover have significantly higher revenues than an ethanol plant that converts all cellulose and hemicellulose to sugars. The opportunity to replace hardwood fiber in pulp production is especially attractive. The fibers have the same length and similar properties.

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.

### POTENTIAL REVENUE Fuel Ethanol and Agri-Pulp

Pro Forma Revenue, \$million 1,000 dry ton/day, 350 days/yr			
	Fuel Ethanol \$0.26/liter (\$1/gal)	Mechanical Pulp \$200/ton	90 Brightness \$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. Lignin is burned for fuel in either case, with the excess energy sold as "green" electricity.

**Keywords:** Corn stover, agri-pulp, biomass, ethanol production

## THE PAST IS A PROLOGUE

At the turn of the 20<sup>th</sup> century agri-fibers from corn stover and wheat straw were a significant source for paper in the mid-west. Corn stover is the material that remains on the surface after the corn grain is harvested. Wood pulp gradually displaced them as a feedstock as the industry matured. The last corn stover pulp mill in Danville, IL closed more than 75 years ago due to economic and environmental problems.

A combination of pulp feedstock shortages and emerging technologies may result in the return of a portion of the industry to the corn-belt again. Over the centuries non-wood feedstock has all nearly disappeared in industrialized nations due to the construction of large plants near the wood source. Less than 3% of US paper production comes from non-wood sources--mainly cotton--for specialty applications.

The Pulp and Paper Industry is under increasing pressure to meet growing demand while complying with environmental issues. Paper production has grown by 189% since 1965. Global per capita demand is expected to grow by 14% over the next decade (Mattoon, 1999), from 51 Kg (112 lbs) to 58 Kg (128 lbs). Where the industry obtains feedstock and how it processes it to paper is a significant concern. In the US, the industry's chip mills are reported by a study team from Duke and NC State Universities to be "mining" the hardwood forests in Southeastern states--removing the trees at an unsustainable rate (Cabbage, et. al. 2000). In addition, the present US paper industry ranks 3<sup>rd</sup> in the release of toxic chemicals, behind chemicals and primary metals (EPA, 1996).

Entrepreneurs are viewing agricultural residues as a low cost feedstock for mini-mills. Using new pulping techniques that are environmentally friendly, they are set on becoming the Nucor Steel of the Pulp & Paper Industry. Their plans include working with growers to collect one million dry tons or more of corn stover within a 50 mile radius, co-locating their pulp plant with an existing ethanol processor that can utilize the fermentation sugars and burn the lignin fraction from the agri-pulp process.

Management of crop residues is becoming increasingly difficult as yields continue to increase. Many now plow it under at extra cost just to remove it from the surface. Producer benefits from selling excess stover can add more than \$100 per hectare (\$40 per acre) even when baling is done with a custom operator. Collection and storage of the residue has been demonstrated on a large scale (Glassner et. al, 1998) at less than \$40 per dry MKg (\$32 per dry ton).

Biotechnology advances have resulted in microorganisms that can convert the pentose sugars from hemicellulose into valuable co-products such as chemicals, plastics and fuel ethanol. Lignin, representing about 20% of the mass, can be burned to supply process energy needs and the excess sold as 'green' electricity. Emissions are expected to be much less than from existing recovery boilers that are burning black liquor from the kraft or sulfite processes.

## CO-PRODUCTS & PROCESS ECONOMICS

A major hurdle for commercialization of biomass to value added products has been the hydrolysis of crystalline cellulose to glucose. While efforts are underway to improve this conversion cost, avoiding it entirely by processing it to agri-pulp for paper products may be an attractive alternative. A proforma for agri-pulp produced paper with fuel ethanol as a co-product using corn stover has significantly higher revenues than an ethanol plant that converts all cellulose and hemicellulose to fermentation sugars.

For a 1,000 dry ton per day plant, converting the cellulose and hemicellulose to fuel ethanol generates \$30 million annually, assuming 26¢ per liter ethanol (\$1 per gallon). The composition of the stover is taken as 38% cellulose and 32% hemicellulose. Current National Renewable Energy Laboratory yields are used:

- Cellulose to glucose, 85%, and glucose to ethanol, 92%
- Hemicellulose to pentoses, 85%, and pentose to ethanol, 85%

Producing mechanical pulp for further processing to paper products increases the revenue to \$66 million. The composition of the pulp will vary depending on the mechanical pulping method. Producing paper with 90 brightness nearly triples the revenue to \$88 million. About 70% of the cellulose is converted to paper. The other 30% is converted to glucose and then fermented to ethanol. The results are shown in TABLE 1.

TABLE 1  
POTENTIAL REVENUE  
Fuel Ethanol and Agri-Pulp

Pro Forma Revenue, 1,000 dry ton/day, 350 days/yr			
	Fuel Ethanol \$0.26/liter (\$1/gal)	Mechanical Pulp \$200/ton	90 Brightness \$800/ton
Cellulose	\$18 million	mix	\$70 million
as EtOH or Pulp	68 million liters (18 million gal)		87,500 dry tons
Other Sugars	\$12 million		\$18 million
as EtOH	47 million liters (12 million gal)		68 million liters (18 million gal)
<b>Total Revenue</b>	<b>\$30 million</b>	<b>\$66 million</b>	<b>\$88 million</b>

The process economics for ethanol are improving. Iogen is beginning operation of a \$25 million CN demonstration plant processing 40 dry tons per day. A recent feasibility study defined a Target Case with "tremendous opportunity" based on previous experience with the construction of corn to ethanol plants over a 25 year period (Vogelbusch USA, 2000).

The Target Case is based on yield improvement, capital cost reduction and lower chemical cost, especially enzymes to lower the fuel ethanol cost to about 25¢ per liter. Yield improvement is most likely to occur with proper pretreatment that removes the largest amount of hemicellulose and still keeps formation of fermentation inhibitors to a minimum.

Locating an agri-pulp plant on site is expected to lower the processing cost of both plants. The capital investment is also projected to be less since the site infrastructure is shared. When an agri-pulp process is considered as part of the process these targets are more easily achieved. Overall process yield is enhanced, less enzyme is required and capital cost is reduced.

One major step is the removal of hemicellulose without shortening the fiber length or damaging the fiber branches. Depithing and acid hydrolysis are suggested approaches. Depithing results in little co-product production. Acid hydrolysis does remove the hemicellulose, converting it to pentose sugars, but the acid can readily damage the fiber. Pretreatment conditions must be less severe, likely producing fewer inhibitors. "High Yield" pulping can leave much of the hemicellulose and lignin with the pulp. More extensive treatment is required to reach the 90 brightness case. In all the cases, enzyme usage is reduced significantly since only the amorphous cellulose is converted to glucose. The crystalline cellulose is taken off for paper production. It is much more difficult to convert to glucose.

## **MARKET DRIVERS**

### Paper Growth

The increasing demand for paper coupled with more sustainable sources is emerging as a major driver for non-wood paper. The North American Market is about 100 million tons of fiber, world wide the market is 300 million tons. It is expected to grow 32% by 2010 (Abramovitz and Mattoon, 1999). The US and Canada produces 35% of the world supply. Data indicates the "electronic office" is not reducing paper usage. The number of pages copied in the US is estimated to be growing at 20% annually, several times greater than the overall market.

In the US, about 40% of paper is made from recycled material, 30% from soft wood and 30% from hardwood. Recycling may improve 5% or so, based on European nations such as Germany with stringent recycling requirements that have attained slightly more than 50%. The producers often own softwood plantations. They are usually well managed, and can be expected to meet the growing needs for softwood. Hardwoods are not grown on plantations in the US and offer an opportunity for replacement with agricultural crops.

### Producer Benefits

As corn yields have increased, the quantity of corn stover has also increased. Corn stover is the largest quantity of biomass residue in the US, 210 million MKg (220 million tons) dry weight, with 30% to 60% available – 66 to 132 million MKg (73 to 146 million tons).

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 bu/ac leaves 4.5 tons of stover per acre. Irrigated areas often exceed 200 bu/ac and 6 to 7 tons of stover remains.

**Residue Management.** To manage the residue, most producers plow the stover under to remove it since it is slow to decompose (Annual CTIC Survey). Many producers agree that removing the stover would allow them to reduce their tillage or go to no-till depending on local factors such as soil type, slope, crop rotation and soil nutrient requirements. Studies by the National Soil Tilth Lab show that more than 80% of the stover remaining on the surface is lost as CO<sub>2</sub> and about 40% of the roots contribute to SOM (Cambardella and Gale, 1999).

Plowing the stover under can cause a deficit in SOM due to oxidation (Reicosky and Linstrom, 1993). A 30 year study of continuous corn showed no difference in the carbon sequestered in the top six 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).

The collection of corn stover does not fit all situations because of erosion concerns and its moisture retention. Where stover is harvested, soil conservation guidelines are followed, leaving 30% or more of the surface covered after collection.

**Stover Value.** 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 \$2.90 to \$3.70 per MKg (\$3.20 to \$4.10 per dry ton) (Hettenhaus et. al, 2000). The 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 on 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 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. At \$0.35 per Kg (\$0.16 per lb) for N fertilizer, is \$2.90 per MKg, about the same value of the nutrients if they are removed. Table 2 summarizes these values.

Table 2  
Corn Stover Value

Basis: 1 dry ton left/acre, Bu/acre. . . . .	130 Bu	170 Bu	200 Bu
1:1 ratio, 16% moisture, sell dry units. .	2 t/ac	3 t/ac	3.8 t/ac
P & K Nutrients, \$3.20/acre . . . . .	\$(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
<b>Total revenue increase/acre</b>	<b>\$84</b>	<b>\$120</b>	<b>\$150</b>

Removing the stover may reduce tillage costs. Avoiding intensive tillage has more savings—for example, one less disking reduces the cost by \$25 per ha (\$10 per acre).

Since 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 3. Table 3 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 3  
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

### Environmental Benefits

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 meet up to 20% of US emission reduction requirements of 500 million metric tons of carbon equivalents.

The market for carbon credits is expected to grow of the next five years and beyond. Using a value of \$10 per ton carbon, the potential benefit to the producer is an additional \$18 to \$31 per acre, shown in Table 4. Carbon sequestration in the soil from corn is \$3 to \$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 to \$27 to the value. No credit is taken for the N fertilizer reduction.

Table 4  
Corn Stover Carbon Credit Potential

Basis: On bu/acre left, 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
<i>Carbon Credit, \$10/ton C</i>			
<i>Sequestration (with less tillage or no-till). . .</i>	<i>\$2.70</i>	<i>\$3.30</i>	<i>\$4.20</i>
<i>Fossil Fuel offset . . . . .</i>	<i>\$15.20</i>	<i>\$21.00</i>	<i>\$26.60</i>
<i>Total Carbon Credit/acre . . . . .</i>	<i>\$17.90</i>	<i>\$24.30</i>	<i>\$31.00</i>

## ENABLING TECHNOLOGIES

### Plant Science

Advances in plant science have increased crop yields and provide the tools to improve fiber characteristics and plant composition for processing. Corn yields continue to increase about 2% per year. 10 MKg per hectare (200 bu per acre) is common, and the record is nearly twice that (Kilman, 2000). Plant geneticists forecast a potential of 600 bu per acre as they increase drought resistance and other conditions that affect plant growth and yield/

Fiber properties of the stalk can be enhanced for pulp processing. The stover fiber length as well as cell wall thickness (coarseness) is close to that of hardwood fibers. A slightly longer fiber than the 1.2 mm average with more branches is desirable to deliver good surface and printability properties to paper, as well as adding stiffness to board. Traditionally, short agri-fibers have been used for board.

However, the short and slender corn stover fibers result in pulp with a high number of fibers per unit weight, guaranteeing good printing properties for the paper. They can potentially produce printing/writing grade pulp with good printing properties and adequate strength. These pulps provide a realistic alternative to hardwood pulps in woodfree printing/writing papers, paperboard and, in some cases, in tissue and newsprint (Paavilainen, 1998, Atchison, 1999).

The relatively low lignin content makes pulping corn fibers easier than wood fibers. Lowering the lignin content and increasing the cellulose composition can increase the yield while requiring less treatment than wood chips.

### Biotechnology

Pentose sugars were generally considered worthless until recombinant fermentation organisms became available. Now there are at least four available. All claim to produce commercial quantities of fuel ethanol and other value added products from these sugars--Purdue University and the USDA Forest Products Laboratory, NREL and BC International. The results have yet to be validated on a large scale. However, yields are expected to increase from 85% to more than 95% as further improvements in performance are made.

Cellulase enzyme technology is also improving the hydrolysis performance for converting cellulose to glucose. A five to ten-fold improvement is expected within the next three years as a result of increased customer interest, DOE funding and the huge market potential for biomass conversion. Converting just 30% of the stover to fuel ethanol at 1.3 ¢ per liter (5¢ per gallon) results in a \$400 million market, the 2<sup>nd</sup> largest worldwide market.

## FUTURE OUTLOOK

Biomass commercialization has been described as similar to infinity--always being approached, but never arriving. Co-production of value added products improves the revenue stream significantly and can help overcome the economic obstacles. Both the fermentation sugar and the agri-pulp markets have huge potential, able to absorb at least 30% of the available stover without concern of being demand limited.

By using proper techniques and equipment, the properties and quality of agri-pulps could be used to replace wood pulp in almost all paper and board grades. The quantity of corn stover, its longer length and larger branches makes it a most attractive feedstock for agri-pulp applications.

Apart from the problem of ensuring sufficient supplies of pulp with specific properties for paper production, there are many political, environmental and economic issues that could lead to better utilization of existing agri-pulp fiber sources. But to make more efficient use of these raw materials in papermaking in the future will require not only investment, but also the adoption of new technology. Optimization of pretreatment for fiber production and sugar processing will also be required.

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## REFERENCES

1. Atchison, Joseph, E., 1999, *Worldwide Progress In Use Of Agricultural Fibers For Manufacture Of Pulp, Paper And Paperboard*, Ag-Fiber Technology Conf, Memphis, TN
2. Cambardella, C. and W. Gale, *Relative contribution of surface residue- and root-derived carbon to soil organic matter under no-till*, 1999, National Soil Tilth Lab, [www.nstl.gov/review/onepage/cam\\_som2.htm](http://www.nstl.gov/review/onepage/cam_som2.htm)
3. Conservation Technology Information Center (CTIC), 1998: *Annual Conservation Tillage Survey News Release*, [www.ctic.purdue.edu](http://www.ctic.purdue.edu)
4. Cabbage, Fred, Robert Abt, P.B. Aruna, Jim Gregory, George Hess, Dick Lancia, Dan Richter, Rex Schaberg, Anthony Snider, Sarah Warren, April 2000, *Economic and Ecologic Impacts Associated With Wood Chip Production in North Carolina*, The Southern Center For Sustainable Forests, <http://taxodium.env.duke.edu/scsf/>, North Carolina State University.
5. Glassner, D., J. Hettenhaus, T. Schechinger, 1998, *Corn Stover Potential for Ethanol Production*, BioEnergy 98 Conference Proceedings.

6. Hettenhaus, J., A. Wiselogel and R. Wooley, *Producer Benefits for the Other Half of the Crop—Corn Stover*, Corn Technology and Utilization Conference, June 2000.
7. Kilman, Scott, Feb 28, 2000, *King of Corn has tips for farmers, but more is not what they need*, Wall Street Journal.
8. Matton, Ashley, 1999, *Paper Production Inches Up*, L. Brown, M. Renner, B. Halweil, ed., Vital Signs, W. W. Norton, New York.
9. Paavilainen, Leena, 1998, *European prospects for using nonwood fibers*, Pulp & Paper International, Miller Freeman Inc, San Francisco.
10. Reicosky, D. C., S. D. Evans, G. A. Nelson, A. R. Wilts and C. D. Wente, 1998, *Soil Organic Matter after 30 years of silage removal from continuous corn and moldboard plowing*, USDA ARS, Morris, MN,
11. US Environmental Protection Agency, 1996 Toxics Release Inventory Public Data release Report, Washington, DC.
12. Vogelbusch USA, 2000, *Building a Bridge to the Corn Ethanol Industry*, NREL subcontract ZXE-9-18080-01, Golden, CO.