# NONWOOD FIBER RAW MATERIALS AND THE BIOREFINERY

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## ABSTRACT

The biorefinery is being touted as the way for the North American pulp and paper industry to reinvent itself. Feedstock for biorefineries includes virtually any biomass including forest waste, bark, fiber bearing sludge, construction waste, municipal waste and nonwood fiber raw materials. Unlike other feedstocks, nonwoods typically are harvested once per year and need to be stored for use year round. This paper explores the issues of securing supplies of nonwood fiber raw materials and delivering them to the biorefinery.

**Keywords:** Nonwood fiber raw materials, Biorefinery

## INTRODUCTION

With increasing concerns about global warming and dwindling supplies of expensive fossil fuels, many countries are actively seeking a new, better and more sustainable energy structure. Virtually every Western country and many Asian and South American countries are investing vast amounts of money in research and development, and in building biorefineries to produce biofuels and bioelectricity from a variety of renewable natural raw materials.

For example, under the US 2005 Energy Policy Act, the DOE is looking into displacing conventional fuel with biofuels by a minimum of 15% by 2017 and more than 30% by 2030. This means that biofuel production must ramp up to about 60 billion gallons (227 billion litres) per year by 2030. And this is only the USA.

Some natural raw materials such as grains (primarily corn), sugarcane and sugar beets can and are being used for bioethanol fuel production. However, the fermentation processes used to convert these raw materials to ethanol require large amounts of process steam and electric power which often are produced using fossil fuels. And, using grains can impact on food prices as they are used in human food as well as livestock feed. Furthermore, there may be limitations on the amount of corn grain ethanol that can be produced in the USA with some predicting a maximum of about 15 billion gallons (57 billion litres) per year.

Renewable biomass resources such as wood waste, agricultural residues and biomass crops are the most plentiful renewable energy resource in the world, a largely untapped resource that can be converted into clean fuels (Fischer-Tropsch biodiesel, biomethanol, bioethanol, biobutanol etc.) and clean power products currently supplied by fossil fuels. Many of these sources are still commonly considered as nothing more than waste products.

There are two platforms that are being developed for biomass to biofuel and bioelectricity biorefineries:

> **ThermoChemical Platform** which uses low or medium temperature gasification or higher temperature pyrolysis to create a high hydrogen content synthetic gas (syngas) that can be used for electricity generation using gas turbines or catalytically converted into liquid biofuels.
>
> **BioChemical Platform** which uses steam, dilute acid, concentrated acid and/or enzyme hydrolysis to convert (depolymerize) the hemicellulose and cellulose of biomass into simpler pentoses (C5 sugars) and glucose (C6 sugars), also called saccarification. These sugars are then fermented and distilled into alcohol (mainly ethanol).

Most of the initiatives for biomass to biofuels are looking into highly efficient (high photosynthesis rate) nonwood plants such as switch grass, miscanthus (elephant grass), Arundo donax (giant reed), cereal straws, corn and other stalks, and other agricultural crops and residuals.

Regardless of the platform, a nonwood fiber-based biomass to biofuel or biopower biorefinery project typically involves the harvesting, baling, transportation, long term storage and preparation of very large volumes of biomass. And, in the case of agricultural residues and many biomass crops, they are typically harvested in 6-8 weeks and need to be stored for an entire year to feed the biofuel or biopower facility.

## BIOMASS REQUIREMENTS FOR BIOREFINERIES

A number of biorefinery projects the may use nonwood fiber raw materials have been studied and/or announced over the past few years including six projects announced by the USDOE in February 2007 that will be receiving Federal government funding [1].
Table 1 provides a partial list of some projects to provide an idea of the volumes of biomass that will be involved in biomass-to-energy biorefinery projects. This list includes some that will use the ThermoChemical platform and others that will use the BioChemical platform. It includes projects that will produce liquid fuels and others that will only produce electricity such as the Laidlaw Berlin project at the former Fraser Paper mill. It is evident that regardless of the platform or the end product, the volumes of cellulosic raw materials will be substantial. These few projects show biomass requirements ranging from 250,000 tons/year to 1.5 million tons/year, and it is very likely that some future projects will require even more.

For the pulp and paper industry, the two phase biorefinery addition to a 1000 ton per day integrated woodpulp and paper mill is of interest [2]. In Phase 1, a biomass to energy gasifier is added to provide reen steam and power for the mill. It would consume about 880,000 dry tons per year of biomass and provide part of the steam and power requirements of the mill. The balance comes from the existing conventional chemical recovery boiler. In addition, the biorefinery would produce a little over 1 million barrels per year of Fischer Tropsch bio-crude. In Phase 2, the conventional recovery boiler is retired and the gasifier capacity is increased to provide all of the steam and power requirements of the mill. Now, the biorefinery is consuming about 1,540,000 dry tons per year of biomass and producing about 2,195,000 barrels per year of Fischer Tropsch bio-crude. The biomass potentially comes from forest residuals as well as agricultural residuals. Connor estimates that there are over 450 integrated pulp and paper mills and another 400-500 nonintegrated paper mills that are good potentials for biorefineries. If all of these mills added biorefineries, I estimate that they could consume between 1.1 to 1.2 billion dry/year of biomass.

From a nonwood fiber pulp and paper perspective, a few years ago, we studied a 200,000 mt/year corn stalks based pulp and paper project in Iowa. The project included a 100,000 bdmt/year corn stalks pulping line that would use about 300,000 mt/year corn stalks. Last year we looked at adding a biorefinery to the project to provide all of the steam and power for the complex. The biorefinery would also produce 819,000 barrels/year of Fischer Tropsch bio-crude. However, the biorefinery feedstock would amount to about 680,000 mt/year corn stalks, more than double that required for pulping. Adding the biorefinery to the project increased the estimated capital investment by about US$ 150 million, but it also increased the estimated Return on Equity (ROE) from 18% to 26% at current light crude oil prices.

The key consideration of these potential projects is that they all will consume large amounts of biomass regardless of the source be it wood residuals, agricultural residues or biomass crops.

## U.S.A. NONWOOD FIBER BIOMASS

The DOE “Billion-Ton Study” provides several scenarios for sustainable biomass availability from agricultural land [3]. Table 2 provides a summary of the total sustainable biomass for various crops and other sources based on land use (acreage), total residue yield per acre, and residue that can be removed on a sustainable basis. The scenarios presented in the study include the current availability as well as the potential availability for moderate to high crop yield increases without land use changes and for moderate to high crop yield increases with land use changes.

The DOE study indicates that the biomass that can be sustainably removed from agricultural lands currently amounts to about 194 million dry tons annually and that this could be increased to nearly 1 billion dry tons within 35 to 40 years through a variety of measures including:

- technology changes such as higher crop yields, adjusting the residue-to-grain (or seed) ratio, improved residue collection technology etc.,
- adoption of no-till cultivation, and
- changes in land use to accommodate the large-scale production of perennial crops such as switchgrass and Arundo donax.

**Table 1 Biomass Requirements for Biorefineries**

<table>
<tr><th colspan="2">Company/Project</th><th>Output</th><th>Biomass Input</th><th>Biomass Source</th></tr>
<tr><td colspan="2">Abengoa Bioenergy Biomass<br>of Kansas, LLC (1)</td><td>11.4 million gal/year cellulosic ethanol</td><td>700 tons/day<br>255,500 tons/year</td><td>corn stover, wheat straw, milo stubble, switchgrass, other</td></tr>
<tr><td colspan="2">ALLICO, Inc.<br>of LaBelle, Florida (1)</td><td>13.9 million gal/year cellulosic ethanol<br>6,255 kilowatts electricity/day<br>8.8 tons hydrogen/day<br>50 tons ammonia/day</td><td>770 tons/day<br>281,000 tons/year</td><td>yard, wood & vegetative wastes<br>eventually energy cane</td></tr>
<tr><td colspan="2">BlueFire Ethanol, Inc.<br>of Irvine, California (1)</td><td>19.0 million gal/year cellulosic ethanol</td><td>700 tons/day<br>255,500 tons/year</td><td>sorted green waste and wood waste from landfills</td></tr>
<tr><td colspan="2">POET (formerly Broin Companies)<br>of Sioux Falls, South Dakota (1)</td><td>31.0 million gal/year cellulosic ethanol</td><td>842 tons/day<br>307,000 tons/year</td><td>corn fiber, cobs, and stalks</td></tr>
<tr><td colspan="2">Iogen Biorefinery Partners, LLC,<br>of Arlington, Virginia (1)</td><td>18.0 million gal/year ethanol</td><td>700 tons/day<br>255,500 tons/year</td><td>wheat straw, barley straw, corn stover, switchgrass, rice straw</td></tr>
<tr><td colspan="2">Range Fuels<br>of Broomfield, Colorado (1)</td><td>40 million gal/year cellulosic ethanol<br>9 million gal/year of cellulosic methanol</td><td>1,200 tons/day<br>438,000 tons/year</td><td>wood residues and wood based energy crops</td></tr>
<tr><td rowspan="2">1000 ton per day integrated woodpulp and paper mill (2)</td><td>Phase 1</td><td>1.1 million barrels/year Fischer Tropsch (Bio-crude)<br>8 MW electricity for pulp & paper mill<br>220,000 lb/hour steam for pulp & paper mill</td><td>2,515 tons/day<br>880,250 tons/year</td><td rowspan="2">forest residuals<br>agricultural residuals</td></tr>
<tr><td>Phase 2</td><td>2.2 million barrels/year Fischer Tropsch (Bio-crude)<br>20 MW electricity for pulp & paper mill<br>500,000 lb/hour steam for pulp & paper mill</td><td>4,400 tons/day<br>1,540,000 tons/year</td></tr>
<tr><td colspan="2">Laidlaw Berlin</td><td>70 MW biomass-energy plant</td><td>1,780 tons/day<br>650,000 tons/year</td><td>wood waste, forest residuals</td></tr>
<tr><td colspan="5">Notes: (1) Approved for DOE funding in February 2007<br>(2) Based on ThermoChem Recovery International, Inc. biorefinery study</td></tr>
</table>

**Table 2 Sustainable Biomass from Agricultural Lands in the U.S.A. (million dry tons/year)**

| Crop | Current | No land use changes | | Land use changes | |
|---|---|---|---|---|---|
| | | Crop yield increase | | Crop yield increase | |
| | | moderate | high | moderate | high |
| Corn grain | 94.6 | 225.2 | 343.2 | 225.2 | 343.2 |
| Sorghum | 0.5 | 3.1 | 6.8 | 3.1 | 6.8 |
| Barley | 0.8 | 3.4 | 5.7 | 3.4 | 6.6 |
| Oats | 0.1 | 0.7 | 1.2 | 0.7 | 1.2 |
| Wheat – winter | 8.9 | 27.4 | 47.5 | 27.4 | 40.9 |
| Wheat – spring | 2.2 | 7.4 | 12.2 | 4.5 | 10.9 |
| Soybeans | 0.2 | 2.6 | 7.9 | 15.3 | 47.9 |
| Rice | 5.7 | 10.3 | 14.7 | 10.3 | 14.7 |
| Cotton linters | 2.7 | 5.5 | 8.9 | 5.5 | 8.9 |
| Other crops | 18.1 | 22.8 | 27.5 | 22.8 | 27.5 |
| Grasses (CRP) | 0 | 25.4 | 25.4 | 15.4 | 15.4 |
| Trees (CRP) | 0 | 2.2 | 2.2 | 2.2 | 2.2 |
| Wood fiber | 0.2 | 0.2 | 0.2 | 9.2 | 9.2 |
| Perennials | 0 | 0 | 0 | 146.5 | 368.3 |
| Manure | 35.1 | 43.5 | 43.5 | 43.5 | 43.5 |
| Fats & greases | 0.9 | 2.0 | 2.0 | 2.0 | 2.0 |
| MSW | 23.7 | 29.4 | 29.4 | 29.4 | 29.4 |
| | | | | | |
| TOTAL | 193.7 | 423.2 | 597.3 | 581.3 | 997.7 |

Notes: 1. Total agricultural land in the U.S.A. amounts to 448 million acres.
2. Other crops are also planted for silage but do not provide biomass for alternative uses.

## NONWOOD FIBER-BASED BIOMASS IS DIFFERENT TO WOOD-BASED BIOMASS

There are some significant differences between nonwood fiber biomass and wood-based biomass that need to be taken into consideration when using nonwood fibers as feedstock for biorefineries. The primary differences are:

1. Trees can be harvested year round in many locations and can be left standing until needed. Thus, wood-based biomass can be available year round from a variety of sources on an as required basis.

2. Agricultural residues and perennial crops, however, typically must be removed from the fields and are harvested in a 6 – 8 week period. These materials must then be stored for the balance of the year or until the next harvest.

3. Agricultural residues and perennial crops such as switch grass typically are baled in large cylindrical or rectangular bales that have relatively low bulk density (10 – 15 lb/ft3) as compared to wood and wood residuals (30 lb/ft3 on a dry weight basis). Regardless, it is possible to achieve a full load weight of 44,000 lbs on a flatbed truck.

4. Depending on harvesting equipment and technique, agricultural residues and perennial crops may be contaminated with dirt and soil during the harvesting and baling process. In the case of gasification or pyrolysis, these

contaminants may not cause any problems but in the case of the biochemical platform acid and/or enzymatic hydrolysis, it is likely that a fiber raw material preparation system will be required to remove as much of the contamination as possible.

5. Nonwood fiber raw materials typically have a moisture content of about 12 – 14% which is much lower than that of green wood.

Nonwood fiber raw materials are very diverse in physical nature and form of delivery. Cereal straws and many grasses typically will be delivered in bales. However, bamboos and giant reeds such as Arundo donax can be chipped in a manner similar to wood. No one system for harvesting, transport and storage will fit all nonwoods.

Based on my experience in the pulp and paper industry, when properly cleaned and prepared nonwood fiber raw material enters the digester, many of the hurdles of producing pulp and paper have been overcome. However, in many instances, economic problems encountered by nonwood-based pulp and paper mills are related to the supply, collection, transportation, storage and preparation of the fiber raw material. I believe that the same will be true for biorefineries regardless of the platform. Taking into consideration the above, the following addresses some of the key issues for using nonwood fiber raw materials in biorefineries. While some of the issues in the following discussion may appear to be obvious, overlooking them may cause the economic failure of a biorefinery project.

Since there is a wide range of nonwood fiber raw materials in terms of physical and chemical characteristics as well as forms of delivery, there are some differing requirements for processing various groupings of nonwood raw materials. It is impossible to cover all of the nonwood fiber raw materials in a single paper so I will focus on cereal straws. However, many of the same issues and considerations apply to other nonwoods.

**Losses Before the Gasifier or Digester**

Losses from the field to the gasifier or digester can have a significant impact on the amount of the nonwood fiber raw material required and the cost of the fiber raw material.

These losses generally can be classified as:

- fiber preparation losses
- storage losses
- transportation losses

In the case of the ThermoChemical platform technologies (gasification and pyrolysis), as mentioned above, it is unlikely that there would be very much fiber preparation loss unless the bales of cereal straw contained a large amount of stones that need to be removed.

But, for the BioChemical platform that includes digesters for acid hydrolysis removal of sand and dirt as well as stones will be important. In a pulp and paper application, for cereal straws that are chopped and then wet cleaned, fiber preparation losses typically can range from 10-15% as we want to remove residual grain and leaves as well as stones and dirt. However, in the biorefinery, the losses may be in the range of 3 – 5% in the preparation system as there may not be a need to remove the residual grain and leaves.

Added to the above losses, one must consider storage losses which, in the case of cereal straws, can typically add another 6 - 10% of losses on the weight of material harvested, and transportation losses that can add a further 2 – 5% of losses.

Once you have determined how much prepared raw material is needed to feed the gasifier or digester, the next step is to develop a clear understanding of the fiber preparation; transportation and storage losses which are critical to establishing how much nonwood fiber raw material must be harvested and delivered to the mill.

**National, Regional and Local Availability**

In Table 2, the current sustainable biomass available from agricultural land in the U.S. is about 194 million dry tons annually and DOE estimates that it could be increased to nearly 1 billion dry tons within 35 to 40 years.

This appears, at a first glance, to be a vast potential fiber resource for biorefineries. However, a number of factors including low bulk density and transportation costs limit the economic collection radius for cereal straws and most other nonwood fiber raw materials to about 60–100 miles. Combining these factors with the fact that available cereal straw yield is only about 1.2–1.9 dry tons per acre makes the following questions very important to selecting a biorefinery site.

a) Where are the regional concentrations of cereal straws?

   In which states are there sufficient quantities of these materials to justify a biorefinery project?

b) Where are the concentrations of the fiber raw material within the region or state?

   For example, straw availability can change substantially from district to district depending on soil types - black, dark brown or brown, geographical location, growing conditions etc.

c) How can farming practices and tillage requirements impact on straw availability within a district?

   If tillage requirements in a particular district are 700 lb/acre straw or 1400 lb, this will have a large impact on straw availability.

d) What are other uses for the straw in the district and how does this affect availability for a new pulp mill?

   For example, the cattle industry in Alberta already consumes a large portion of the available wheat straw. Also, one may not want to locate near another large industrial user.

e) What is your fall-back position to account for year-to-year growing conditions, rotational crop practices or a drought?

Responses to these questions will establish several areas which have sufficient straw within a reasonably economic collection radius.

The next step is to determine how the straw will be harvested, transported and stored until it is needed, and how the farmers will be paid for the straw. These issues raise numerous other questions which will affect either the operating and/or capital costs of the mill. And, before these issues can be addressed, the method of securing the straw supply must be established.

**Securing Long Term Supply**

There are many methods that a biorefinery can use to contract for the straw supply such as:

a) direct purchasing from farmers
b) purchasing through farmer coops
c) purchasing through an intermediary such as a custom baler

There are pros and cons for each method. For example, for direct purchasing from farmers, the mill will require a large purchasing department which has an extensive knowledge of the farm community. Purchasing through an organized coop may lessen the demands on the mill's purchasing department. And, purchasing through an intermediary will add costs.

The next general issue will be the form and term of the contract. This depends largely on the method of contracting used; however, the contracts should be as long as possible to ensure long term supply.

**Harvesting, Baling & Transportation**

Baling is the typical method for handling straw and most other nonwood fiber raw materials with the exception of bamboo, giant reeds and cane. Harvesting agricultural residues and fiber crops typically takes place over a 6-8 week period. This short time frame raises a number of questions:

a) Who will do the harvesting and baling?

   In some instances, this will be done entirely by the farmer. In other instances, custom balers may be used and, in other instances, the mill itself may own the equipment to bale the straw.

b) Is there enough farm equipment and balers of the type required to bale the straw during the harvesting season?

   If not, the mill may have to include additional equipment in its capital costs.

c) Are there enough trucks locally to transport the baled straw to the mill as it is harvested?

d) Can the local infrastructure (roads) support the truck traffic for moving all of the required fiber raw material to the mill as it is harvested?

e) Will all of the baled straw be stored at the mill or will off-site storage be used for the bulk of the straw with only about 2-4 weeks supply on-site?

The answer to these questions affects many issues such as:

- when the farmers would be paid fully for the straw which can affect working capital requirements
- storage conditions and quality control
- land requirements for storage at the mill which affects capital costs

**Bales versus Pellets**

Although baling is the typical method for handling straw and most other nonwood fiber raw materials, some projects are considering pelletizing the biomass to increase the bulk density from 10 – 15 lb/ft3 for baled straw up to as much as 30 lb/ft3. They believe that using pellets will also permit handling and transporting the biomass in a manner similar to coal which would reduce the costs associated with handling and transporting bales.

While these factors could reduce handling and shipping costs to the extent that the biomass could be transported economically over much larger distances, delivering hard, dense pellets to the biorefinery could cause other problems.

For example, in the BioChemical platform, some hydrolysis reactions will only work if the biomass has about 30% moisture content throughout. It is very unlikely that it will be possible to increase the moisture content of hard, dense pellets to this level without first opening up the structure of the pellets in some manner prior to the digester. This will require a newly designed preparation system prior to the digester and there will be added power requirements to run the system. The question is whether or not this system will work if the lower cost of the biomass offsets the added capital, energy and maintenance costs.

For the ThermoChemical platform, hard, dense pellets will have a different burn rate than lower density biomass. Again, it may be necessary to break up the pellets prior to the gasifier or pyrolysis unit in order to get proper firing. As lower moisture is beneficial in this platform, the preparation system would be a mechanical unit that may require a large amount of energy.

Pelletizing may offer some real advantages to the handling and transport of biomass, But, from my perspective, while there are possible solutions to preparing pellets prior to the biorefinery regardless of the platform, these solutions have not been tested as yet and it would be premature to base a biorefinery project today on using pellets.

**Storage**

Straw bale piles may contain 500 to 3,000 tons. Since the straw on the bottom and outside layers of the piles deteriorates with time, deterioration will be less if larger piles are used. Large straw piles are usually about 12 m high, 20-22 m wide and about 160 m in length, tapering toward the top for stability. Piles are spaced 20 to 30 m apart to reduce the fire hazard and to permit access for fire fighting equipment.

If rainfall is moderate to high, it is preferable to protect the top of the piles with metal or plastic covers. Some mills go to the extent of piling straw in open-sided or semi-open sheds for protection from the weather; however, the substantial capital cost and high degree of manual labor is rarely justified.

Chemical preservatives, such as borax, can be used to reduce straw deterioration; however, the cost rarely justifies their use.

Straw bale handling and storage losses are usually in the order of 2.5-5%.

**Long Term Mill Storage Versus Off-Site Storage**

a) <u>Long Term Mill Storage</u>

The advantages of having all of mill's annual requirements for straw stored on-site are:

- the mill has effective control of its raw material supply

The disadvantages of having all of mill's annual requirements for straw stored on-site are:

- intense pressure on the collection and transportation system may increase costs
- a large amount of working capital is tied up in inventory
- a large area is required for straw storage - a biorefinery using 350,000 tons/year of baled straw would require an on-site storage area in the order of 200 – 225 acres
- the large storage area substantially increases on-site material handling requirements
- very large on-site straw storage area substantially increases the fire hazard

b) Long Term Off-Site Storage

The advantages of using off-site storage at farms and/or intermediate collection depots:

- less pressure on the transportation system during harvesting
- lower amount of working capital is tied up in inventory if farmers are fully or partially paid as the straw is delivered to the mill
- small short term storage area required at the mill

The disadvantages of using off-site storage are:

- the mill has less control of its raw material supply
- maintaining straw quality at numerous locations becomes more difficult - establishing requirements and monitoring by the mill will be necessary
- straw delivery to the mill on a daily basis must be well organized in advance

In our experience with pulp and paper applications, long term off-site storage usually turns out to be the better alternative provided that effective controls can be put in place for maintaining quality and daily delivery.

## Raw Material Cost Components

Hurter [5] identified that the cost nonwood fiber raw material charged to the digesters in a pulp mill is composed of several components:

- base price paid to the farmer
- cost of harvesting and baling
- cost of collection and transportation
- cost of storage
- cost of fiber preparation

Similar costs will be encountered by the biorefinery.

The cost distribution will vary depending on circumstances, contractual arrangements and the fiber raw material. For cereal straw, the base price, harvesting and baling often are lumped together as they are within the farmer's control, and collection and transportation may be by the farmer or by the mill. But, in some instances, harvesting and baling may be under the mill control or that of independent contract balers.

It is critical however that none of the cost components is overlooked regardless of how they are distributed.

## SUMMARY

The foregoing highlights some of the critical issues that must be addressed in order to develop a sustainable, long term supply of nonwood fiber raw material to a biorefinery.

The goal is to create a win-win situation between farmers and the biorefinery to ensure that the farmers are adequately compensated for their fiber raw material and that the biorefinery receives the material at a reasonable cost on a sustainable basis such that it makes the biorefinery economically viable over the long term.

While the challenges are large, they are not insurmountable as they have been addressed successfully at many pulp and paper mills around the world.

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