Considerations For The Use of Nonwood Raw Materials for Tissue Manufacture

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ABSTRACT

The abundant nature of wood resources in the US makes it difficult for nonwood alternatives to compete economically as a raw material for paper manufacture. However, in cases where wood fibers cannot deliver selected sheet properties, there are opportunities for nonwoods. Selected nonwoods, grown domestically, could offer US tissue manufacturers an alternative to imported short and long fiber and offer a product with "green" appeal. This article discusses the general types of nonwoods, those that might be suitable for tissue manufacture, and the challenges associated with the use of nonwoods.

INTRODUCTION

Tissue is a critical product for the pulp and paper industry worldwide. In the United States, 7.3 million tons of tissue were produced in 2011 (1), primarily from wood fibers. Wood has proven to be a robust and sustainable source of all papermaking fibers, and selected wood species are particularly well-suited for the manufacture of tissue. In the US, premium tissue brands are typically made mainly from imported bleached eucalyptus kraft (BEK) pulp, which imparts superior softness, and a small amount of (mostly imported) bleached northern softwood kraft (NBSK), which imparts strength and runnability without compromising softness.

With these advantages, there is no doubt that much tissue will continue to be made from wood-based raw materials in the future. However, two key drivers are leading to an increased interest in the use of wood alternatives – nonwoods – as a source of fibers for tissue manufacture:

- *Raw Material Security* – Currently, premium tissue manufacturers in the US rely almost entirely on other countries for their pulp raw materials (Brazil for BEK, Canada for NBSK). While there is no anticipated problem with the supply chain, such manufacturers are not happy with having no domestic fiber backup or alternative. There is thus interest in finding suitable raw materials that can be sourced domestically.
- *"Green" Marketing* – Despite considerable data to the contrary, some consumers believe that the use of wood for paper products, including tissue, is bad for the environment. Consumer product companies, rather than fighting this misinformation, often try to leverage consumer sentiments to increase market share with some type of "green" product. It is thus believed that a nonwood-based tissue product, at the same or perhaps slightly higher cost, could be attractive in the marketplace.

The purpose of this paper is to introduce readers to the various types of nonwoods, describe what attributes of some of them might be useful for premium tissue manufacture, and present the challenges associated with using nonwoods instead of wood raw materials.

Types of Nonwoods for Papermaking

In general, nonwood fibers are obtained from annual plants which are planted and harvested within one growing season. Some are somewhat like perennials in that they yield fiber annually for some number of years. What they all share in common is that they provide a raw material yield much faster than wood. They can be divided into the following two categories:

Agricultural Residues -- These materials remain after the principal crop (usually cereal or grain) has been harvested. Examples include rice and wheat straw, corn stalks, flax straw, and sugar cane (bagasse).

Fiber Crops -- These materials come from crops planted specifically to yield fiber. Examples include industrial hemp, kenaf, and bamboo.

Table 1 shows some of the physical properties for different nonwood fibers (2).

Agricultural residues. (3)
Agriculture residues generally tend to have slender, fragile fibers with an average length of 0.5 -1.5 mm. Wood fibers, on the other hand, have coarser and stronger fibers with an average length of 0.8 - 6 mm. Residues also tend to have with a high content of extraneous materials like fines, silica, and pith, which can cause problems in processing. Their drainage rate is usually significantly lower than for wood pulps, and the number of recycles possible is limited. With these low-end characteristics, one might wonder why agricultural residues are worth consideration. The answer is simple, when the following facts are taken into consideration:

1. *They are already paid for* -- The growth costs and some harvesting costs of agricultural residues are paid for by the principal crop. This subsidy gives residues a real advantage with respect to raw material supply costs.
2. *They are widely available in abundance* -- As leftovers from grain processing, these residues are available in many areas of many countries. Table 2 shows the availability of a variety of agricultural residues in the United States (4).
3. *They are already being made into pulp and paper products* -- Since residues are the only major source of papermaking fiber in countries like China and India, they have long been used to make a wide variety of paper products. The conversion of residues is therefore not a developmental issue or a mystery, but a well-established technology.
4. *They are causing environmental problems in some areas* -- In some areas of the country, all the available residue material cannot be plowed under as natural fertilizer. Similarly, there are frequently no livestock outlets for the material. In these cases (and often to reduce insect and nematode growth), farmers have traditionally burned off the residues. The very obvious pollution produced in this manner, along with some recent discoveries of serious health effects posed by the smoke, has led to legislation phasing out burn-off practices. With no useful outlets for the residues, farmers will end up with a serious disposal problem. This situation gives more strength to the case for using residues for making products like paper or fiber board.

Fiber crops. (3)
Fiber crops are another story. They have to yield a return to the farmer based on fiber value alone, so there is much concern about whether the price paid per ton and the yield per acre will result in a pulp cost competitive with that for wood pulp. The quality of fiber crop pulps tends to be good, with fiber length and coarseness, strength, and drainage often matching and exceeding softwoods. However, some fiber crops that have attracted much interest in the past -- kenaf and industrial hemp -- have an interesting physiology that must be considered. Instead of a uniform fiber distribution such as is found in hard- and softwoods, these materials have two very different fiber types. Bast fibers, found in the outer bark, are long and tough, with an average fiber length of 2.5 - 20 mm. Core fibers, found in the woody inner stem of the plant, are shorter, with an average fiber length of 0.5 - 1 mm. In the face of this bimodal distribution, questions are raised regarding the processing of fiber crop materials. Should bast and core be separated prior to pulping? Is the added capital expense worth the benefit? If separation is not used, is the quality of either or both fractions compromised?

Some fiber crops have fiber dimensions and bonding/strength properties that make them even better candidates for papermaking than wood. In a classic analysis, Atchison (5) showed that abaca, an inedible banana also called manila hemp, had properties far better than softwoods, while sisal and kenaf bast were comparable to or better than softwoods. However, the low yields and/or high processing costs for these raw materials makes the pulp cost much higher than for wood.

It should be mentioned that one category of fiber crops, the so-called “woody nonwoods,” is of special interest, and interest in these raw materials is growing. This category includes nonwoods that are not loose and bulky, like straws and grasses, but have a higher bulk density and are physically more like wood. Examples of such crops include bamboo, reed, and switch grass. The advantage of woody nonwoods is that they tend to have higher growth yields than for other nonwoods, and they can be chipped and processed in existing pulp mills with little or no modification. Moreover, many of them are perennial crops which produce an annual yield and require replanting only occasionally.

Nonwoods for Tissue Manufacture

The manufacture of tissue, especially premium grades, requires unique fiber properties in order to impart a high degree of softness while maintaining enough wet strength for machine runnability and dry strength in the final product. Some generally-accepted properties include: high length-to-width ratio (high slenderness), low coarseness, optimum fiber count (fibers per gram), low fines content, and good drainage.

Nonwoods are already being used for medium-quality tissue manufacture in some countries where wood resources are not plentiful. These products typically contain 60-80 % sugar cane bagasse or wheat straw pulp, with the remainder being bleached chemical pulp from wood (6). But there is increasing interest, especially in the US, to find domestic nonwoods that could be used to produce tissue with premium softness. Such an accomplishment will require suitable substitutes for the long fiber (NBSK) and the short fiber (BEK). Some of the tissue currently sold in the US has some or mostly bagasse fiber content, and there are reports of other tissue products made from bamboo fiber.

Nonwood substitutes for NBSK must have a combination of sufficient fiber length for bonding and strength as well as lower coarseness and wall thickness to maintain softness. Table 3 shows the average fiber length and coarseness values for various woods and nonwoods (7). Clearly, some of the nonwoods (Hesperaloe, for example) have fiber length comparable to NBSK, but with much lower coarseness. In fact, it has been shown that premium-quality tissue can be manufactured with Hesperaloe being substituted for NBSK (7).

International fiber consultants HurterConsult Incorporated have analyzed some possible candidates for NBSK replacement (6). Table 4 presents these candidates, along with comments about the possible opportunities and challenges for each. Table 5 shows some fiber properties for these materials. Of the candidates, it is likely that only bamboo, hesperaloe, and kenaf could be feasibly grown in the US, given climate, land, legal, and other considerations.

Nonwood substitutes for eucalyptus (BEK) must have a combination of moderate fiber length, high slenderness, low coarseness, and an optimum fiber count. Table 6, from HurterConsult, shows some candidates, and Table 7 shows their fiber properties. All of these nonwoods are currently grown or could be feasibly grown in the US.

The Challenges of Using Nonwoods

Currently, tissue is made from nonwoods primarily in countries without extensive wood resources and economic access to wood-based pulp. The reasons are straightforward – the use of nonwoods for the manufacture of any non-specialty paper product in the US, as compared to wood, faces significant feasibility and economic challenges, including:

1. *Raw Material Availability* – Wood is abundantly available in the US, with growth rates exceeding consumption rates by about 37 % . While some nonwoods – mainly agricultural residues – are plentiful in the US, others are not yet established as a commercial crop.
2. *Harvest and Storage* – Wood, for the most part, is stored on the stump. In many areas of the country, it can be harvested year round. Thus, it is not necessary to maintain large inventories. Many nonwoods must be harvested all at one time in order to prevent field-based decomposition or interference with future plantings. This requires extensive storage facilities, which adds to the cost. Large inventories of nonwoods are susceptible to fires, natural disasters, and pests.
3. *Bulk Density* – With the exception of the woody nonwoods, most nonwood raw materials are bulky. This makes transportation and storage expensive. Coupled with low per-acre yields, low bulk density limits the collection radius for raw materials and restricts the practical size of new mills to 250 tons per day. Such small mills have a hard time competing with much larger wood-pulp mills. In addition, bulky materials cannot typically be pulped and processed in existing equipment designed for wood chips, without extensive modification. This means that such nonwoods cannot simply be blended with wood chips or substituted for wood in existing mills.
4. *Extraneous Materials* – Once the bark is removed, wood is a very clean raw material, with very low contents of non-fibrous components like ash, silica, and pith. Some nonwoods have high contents of such components. Bagasse and corn stalk, for example, can contain up to 25 % pith by weight. The pith

consumes chemicals and severely limits drainage rates, so it must be removed prior to pulping. Some cereal straws can contain up to 20 % silica by weight. The silica rapidly fouls processing and heat transfer equipment, necessitating frequent acid washes or some type of desilication process. All of these additional processing steps further increase the cost of nonwood pulps, relative to wood.

5. *Fines Content and Fiber Fragility* – Some agricultural residues have a high content of fines (primary fines), and they tend to break up during processing, generating more (secondary fines). These fines limit the drainage rate of the pulps, requiring larger equipment for washing and dewatering. Also, the more fragile nature of the fibers means that the products made from them cannot be recycled as many times as wood-based products, which can affect the life cycle analysis of the nonwood products.
6. *Raw Material Variability* – While there is definite variability in the properties of wood, it is far less than that noted for annual crops. The chemical and physical composition of many nonwoods can vary widely, based on factors during the growing season (climate, water, fertilization, etc.). Such variability can offer challenges in processing.
7. *Risk* – With the exception of wide-spread fires or massive storms, in general the wood supply in the US is fairly decoupled from environmental fluctuations. This makes it a low-risk raw material for the paper industry, which in turn leads to low wood cost. Annual crop availability is heavily dependent upon year-to-year environmental fluctuations. Massive drought, flooding, or pest attack could greatly reduce the availability of some nonwoods, driving up cost and adding risk to the papermaking process.

Bamboo is of Great Interest

Recent market developments have greatly increased the interest in bamboo as a raw material for papermaking, especially for tissue. One of the advantages of bamboo is that there are over 1250 species grown worldwide (7). The species yield a wide variety of fiber properties, from hardwood- to softwood-like, so there is an opportunity to produce a paper product with both strength and smoothness/softness using one raw material – just like wood. Table 8 shows the fiber properties of some bamboo species (8). Table 9 shows the chemical properties of three bamboo species (8).

As a raw material for papermaking, bamboo does not suffer from many of the disadvantages of other nonwoods, namely:

- *Bulk density* – As a woody nonwood, bamboo is more like wood than straws and bast fibers. It can be economically transported and stored. It has been proven that bamboo can be processed in wood-based equipment or co-cooked with wood chips.
- *Availability* – Yields for bamboo stands have been reported to be as high as or higher than for southern pine. Bamboo can be harvested annually for a number of years, without replanting. Bamboo, like wood, can be left standing until it is needed so long term storage is not required as in the case of annual agricultural residues. Although bamboo is not currently grown intensively in the US, this situation may change rapidly (see below).
- *Extraneous Materials* – Compared to agricultural residues and some fiber crops, bamboo is remarkably free of pith and fines. Although the ash and silica content is higher than for wood, it is still low enough to be manageable.

One important aspect of bamboo is its appeal to farmers/growers. Rather than having to wait 20-30 years for southern softwoods to reach a suitable maturity for pulping, farmers planting bamboo can have an annual food crop (shoots) and a fiber crop each year after a three-year induction period, and they would only have to replant the crop every 20-35 years. Although it is often characterized as an invasive species, bamboo is easily contained with well-known techniques, and it can be eliminated from a growing plot by intensive plowing.

Summary

In general, it is difficult for nonwood raw materials to compete with wood as a raw material for papermaking. However, when wood cannot deliver key attributes necessary for selected grades, there are opportunities for the use of nonwoods. For the US tissue industry, some nonwoods may offer attributes similar to those for imported BEK and NBSK, giving the industry a raw material that is totally sourced domestically. In this regard, bamboo is receiving a lot of attention from the industry.

References

1. RISI Global Statistics Database.
2. Isenberg, I. H., Pulp and Paper Microscopy, The Institute of Paper Chemistry, Appleton, WI, 1967.
3. Byrd, M. and Gratzl, J., Nonwood Fibers Offer Opportunities and Challenges, Paper Age, 14(7): 20-22, 1998.
4. Rowell, R. M. and Cook, C. 1998. Proceedings of the North American Nonwood Fiber Symposium, 17-18 Feb. 1998, Atlanta, GA. TAPPI Press, Atlanta, GA., pp. 43-47.
5. Atchison, J. E., "Data on Non-Wood Plant Fibers," Chapter 2 in Pulp and Paper Manufacture, Vol. 3: Second Fibers and Non-Wood Pulping," Joint Textbook Committee of the Paper Industry, Atlanta, GA and Montreal, Que. Canada. pp. 4-21.
6. www.hurterconsult.com
7. Reeves, R. H. et al., "Soft high strength tissue using long-low coarseness hesperaloe fibers," U.S. Patent # 5,320,710, 1994.
8. Bhargava, R. L., "Bamboo," Chapter 5 in Pulp and Paper Manufacture, Vol. 3: Secondary Fibers and Non-Wood Pulping," Joint Textbook Committee of the Paper Industry, Atlanta, GA and Montreal, Que. Canada. pp. 71-81.
9. US Forest Products Laboratory Data, http://www.fpl.fs.fed.us/documnts/pdf1984/pette84a.pdf .

Table 1. Physical properties of some nonwood fibers (2).

Common name (Scientific name)	Fiber length (mm)		Fiber width (mm)	
	Avg	Range	Ave	Range
Ramie (*Boehmeria nivea*)	120	60~250	50	11~80
Flax (*Linum usitatissimum*)	33	9~70	19	5~38
Hemp (*Cannabis sativa*)	25	5~55	25	10~51
Ceiba, kapok tree (*Ceiba pentandra*)	19	8~30	19	10~30
Cotton lint(*Gossypium* spp.)	18	10~40	20	12~38
Paper-mulberry (*Broussonetia papyrifera*)	10	6~20	30	25~35
Sunn (*Crotaria juncea*)	8	4~12	30	25~50
Abaca (*Musa textilis*)	6	2~12	24	16~32
Kenaf (*Hibiscus cannabinus*)	5	2~6	21	14~33
Sidal (*Agava Sislana*)	3	1~8	20	8~41
Bamboo (*Dendrocalamus arundinacea*)	2.7	1.5~4.4	14	7~27
Raphia (*Raphia hookeri*)	2.4	-	30	17~46
Sabai (*Eulaliopsis binata*)	2.1	0.5~4.9	9	4~28
Common reed (*Phragmites communis*)	2.0	1.0~3.0	16	10~20
Jute (*Corchrous caspsularis*)	2	2~5	20	10~25
Papyrus (*Cyperus papyrus*)	1.8	1.0~4.0	12	8~25
Sugar cane (*Sacchrum officiarum*)	1.7	0.8~2.8	20	10~34
Corn (*Zea mays*)	1.5	0.5~2.9	18	14~24
Rice (*Oriza sativa*)	1.4	0.4~3.4	8	4~16
Wheat (*Triticum sativum*)	1.4	0.4~3.2	15	8~34
Esparto (*Stipa tenacissima*)	1.2	0.2~3.3	13	6~22
Albardine (*Lygeum spartum*)	1.1	0.2~3.1	12	6~21

Table 2. Availability (1998) of agricultural residues in the US (4)

Stalk Residue	Dry Tons Per Year
Corn	300,800,000
Wheat	78,900,000
Barley	12,000,000
Sorghum	12,000,000
Oat	6,000,000
Rice	7,500,000
Cotton	7,100,100
Flax	700,000
Rye	400,000
Grass	900,000
Sugar Cane Bagasse	3,000,000

Table 3. Fiber length and coarseness values for wood and nonwood materials (7)

Material	Coarseness, mg/100 m	Avg. Fiber Length, mm
Northern Softwood Kraft (NSWK or NBSK)	14.2	2.92
Southern Softwood Kraft (SSWK)	26.7	3.46
West Coast Softwood Kraft (WCSK)	23.2	3.38
Northern Hardwood Kraft (NHWK or NBHK)	11.0	1.02
Eucalyptus	7.6	0.99
Abaca	17.4	3.65
Industrial Hemp	13.8	3.36
Sisal	14.0	2.45
Yucca elata	6.7	1.89
Hesperaloe changii	9.0	4.58
Hesperaloe funifera	8.0	2.96

Table 4. Some possible nonwood substitutes for Northern Bleached Softwood Kraft (6)

Material	Comments
Abaca	• Very high strength • Expensive (4-5 times wood pulp) • Limited raw material and market availability
Bamboo	• Over 1250 species • Some with fiber length similar to NBSK • Can be processed in woodpulp mill • Can economically establish bamboo farms
Industrial hemp bast	• High strength • Expensive (3 times wood pulp) • Limited raw material and market pulp availability • Illegal to grow in most of USA
Hesperaloe funifera	• High strength – similar to or better than NBSK • US Patent 5,320,710 "Soft high strength tissue using long-low coarseness hesperaloe fibers" – James River 1994 • Limited raw material availability • Could be cultivated in Mexico on marginal land
Kenaf bast	• Strength similar to NBSK • Expensive pulp due to decortication • Limited raw material availability • Annual crop
Sisal	• High strength • Very expensive (3 times wood pulp) • Limited raw material and market pulp availability

Table 5. Fiber properties for some possible NBSK substitutes (6)

	Length, mm			Diameter, microns			L/D Ratio
	Max.	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	
Abaca	12.0	2.0	6.0	36	12	20	300:1
Bamboo	3.5 - 9.0	0.38 -2.5	1.36 -4.0	25 - 55	3 - 18	8 - 30	135 - 175:1
Hemp bast	55.0	5.0	20.0	50	16	22	1000:1
Hesperaloe funifera			3.2			15	215:1
Hesperaloe changii			4.6				
Kenaf bast	7.6	0.98	2.7			20	135:1
Sisal	6.0	1.5	3.0			17	180:1
Softwood	3.6	2.7	3.0	43	32	30	100:1

Table 6. Some possible nonwood substitutes for Bleached Eucalyptus Kraft (6)

Material	Comments
Arundo donax (giant reed)	• Can be processed in woodpulp mill • Can economically establish Arundo farms • Considered an invasive species in US
Sugar cane bagasse	• Requires depithing (about 32% pith cells) • Competes as a fuel source
Bamboo	• Over 1250 species • Some with fiber length similar to BEK • Can be processed in woodpulp mill • Can economically establish bamboo farms
Corn stalks	• Very large volume available in USA; agricultural residue • Reasonable delivered cost • Contains 18 – 22% pith cells; depithing required • Harvested in 6 – 8 weeks and needs to be stored until use
Sorghum stalks	• Moderately large volume available in USA; agricultural residue • Contains pith cells; depithing required • Harvested in 6 – 8 weeks and needs to be stored until use
Wheat straw	• Large volume available in the USA; agricultural residue • Silica content may be a problem; new desilication processes available • Harvested in 6-8 weeks and needs to be stored until use

Table 7. Fiber properties for some possible Bleached Eucalyptus Kraft substitutes (6)

	Length, mm			Diameter, microns			L/D Ratio
	Max.	Min.	Avg.	Max.	Min.	Avg.	
Arundo donax			1.18			15	78:1
Bagasse	2.8	0.8	1.7	34	10	20	85:1
Bamboo	3.5 - 9.0	0.38 -2.5	1.36 -4.0	25 - 55	3 - 18	8 - 30	135 - 175:1
Corn stalks	2.8	0.68	1.26	20	10	16	75 :1
Sorghum stalks			1.65	80	30	47	35 :1
Wheat straw	3.1	0.7	1.5	24	7	13	110:1
Hardwood	1.8	1.0	1.2	50	20	25	50:1

Table 8. Fiber properties for some bamboo species (8)

Species	Avg. Length, mm	Avg. Width, microns	Avg. Lumen Width, microns	Avg. Cell Wall Thickness, microns
Bambusa arundinaria	1.73	22	6	8
Bambusa blummeana	2.02	18	4	7
Bambusa vulgaris	2.33	17	4	7
Gigantochloa aspera	3.78	19	7	6
Phyllostachus bambusoides	0.64 – 1.64	8.9 - 21	---	---
Phyllostachys nigra	1.86	19	6	6.5
Schizostachyum lima	1.67	22	4	9
Schizostachyum lumampao	2.42	14	6	4

Note: If a range is shown, it is for the different regions of the plant (top, middle, base, nodes)

Table 9. Chemical properties for some bamboo species (8), with eucalyptus shown for comparison (9)

	Bambusa arundinacea (Dowga)	Dendrocalamus strictus (Medar)	Monostigma oxygenanthera (Chiva)	Eucalpytus
Hot water solubility, %	6.5	5.8	4.9	7
Alcohol-benzene solubility, %	5.5	4.3	2.9	4
1 % NaOH solubility, %	24.9	24.0	25.4	16
Lignin, %	24.6	26.6	27.5	22
Pentosans, %	17.2	17.7	17.5	14
Holocellulose, %	68.8	67.3	72.0	72
Ash, %	2.7	4.1	3.9	0.2
Silica, %	1.9	2.5	2.3	negl.

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Tissue 360° Forum at PaperCon 2013

Topics to be Covered

- Why This Presentation? Why Nonwoods & Tissue?
- An Introduction to Nonwoods
- Possible Nonwoods for Replacement of Northern Softwood
- Possible Nonwoods for Replacement of Eucalyptus
- Bamboo – Growing Interest
- Challenges of Using Nonwoods
- Summary

Why This Presentation?

- In North America (and many other places globally), wood is an abundant, inexpensive, and perfectly suitable source of fiber for papermaking
- This means that alternatives to wood – the so-called “nonwoods” – cannot compete as a raw material
- The exception: Those cases where nonwoods offer special properties not available from the domestic wood supply
- TISSUE is one such promising opportunity

Premium Tissue – A Special Case

- Premium tissue grades offer consumers superior softness with good strength
- Two fiber types provide this combination of properties
  - Bleached Eucalyptus Kraft (BEK) – Imported from Brazil, offers a high degree of softness that cannot be easily matched by mixed North American hardwoods
  - Northern Bleached Softwood Kraft (NBSK) – Imported from Canada, offers good strength and runnability, but without the loss of softness that comes from many US softwoods
- Since the US wood supply cannot provide the desired sheet properties…can nonwoods offer an alternative?

What Is Driving This Interest?

- Raw Material Security – US tissue manufacturers are somewhat uncomfortable that their entire furnish for premium grades comes from foreign suppliers
- “Green” Marketing – Some consumers believe that making paper (especially consumer grades like tissue) from wood is bad for the environment; even though this is untrue, it offers a marketing opportunity

An Introduction to Nonwoods

Tissue 360° Forum at PaperCon 2013

What Are "Nonwoods?"

- Plant materials not associated with "perennial" forests; can be annual or perennial
- Are grouped into two categories
  - Agricultural Residues – stem, stalk, or other materials left over after a principal crop (grain, see, oil, etc.) has been harvested
  - Fiber Crops – plants grown specifically for fiber production

Agricultural Residues

US Ag Residue Availability 1998

Stalk Residue	Dry Tons Per Year
Corn	300,800,000
Wheat	78,900,000
Barley	12,000,000
Sorghum	12,000,000
Oat	6,000,000
Rice	7,500,000
Cotton	7,100,100
Flax	700,000
Rye	400,000
Grass	900,000
Sugar Cane Bagasse	3,000,000

Rowell & Cook, 1998 TAPPI North American
Nonwood Fiber Symposium

Table 4. Dimensions and chemical composition of some common agro-fibers[1]

Type of Fiber	Cellulose (%)	Lignin (%)	Fiber Dimension (mm) Mean Length	Mean Width
Cotton	85-90	0.7-1.6	25	0.02
Seed Flax	43-47	21-23	30	0.02
Hemp	57-77	9-13	20	0.022
Abaca	56-63	7-9	6.0	0.024
Coniferous wood	40-45	26-34	4.1	0.025
Sisal	47-62	7-9	3.3	0.02
Bamboo	26-43	21-31	2.7	0.014
Kenaf	44-57	15-19	2.6	0.02
Jute	45-63	21-26	2.5	0.02
Esparto	33-38	17-19	1.9	0.013
Papyrus	38-44	16-19	1.8	0.012
Sugar cane bagasse	32-37	18-26	1.7	0.02
Cereal straw	31-45	16-19	1.5	0.023
Corn straw	32-35	16-27	1.5	0.018
Wheat straw	33-39	16-23	1.4	0.015
Rice Straw	28-36	12-16	1.4	0.008
Esparto	42-54	17-19	1.2	0.013
Deciduous wood	38-49	23-30	1.2	0.03
Coir	35-62	30-45	0.7	0.02

[1] Listed by increasing mean fiber length

Rowell & Cook, 1998 TAPPI North American Nonwood Fiber Symposium

Wheat
Straw

Corn Stover
(stalk, leaves, husks)

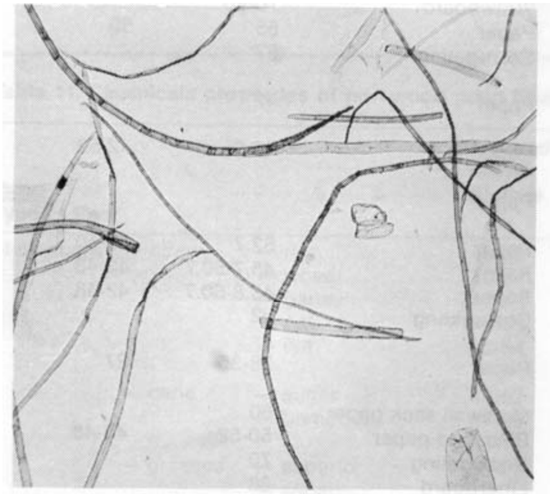
Sugar Cane Bagasse

Potential Advantages

- Cost is lower because main crop (seed or grain) pays for planting, harvesting costs
- In some areas, residues are causing disposal problems (burning, landfilling)
- Selling them for papermaking brings in additional revenue for the farmer

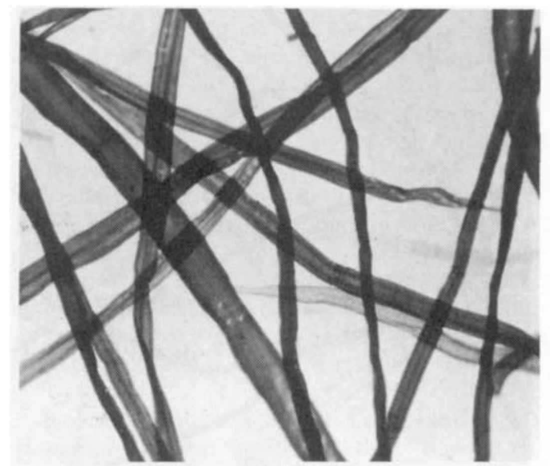
Problems

- Fibers tend to be short, slender, thin-walled – have low strength and poor recyclability
- Some residues have a high content of fines, parenchyma – poor drainage, yield
- Some have a high content of silica – deposits heavily on processing equipment
- Most have low bulk density compared to wood; can't process in existing wood –based equipment



Wheat straw fibers

Southern pine fibers



Atchison, J. E. 1983. Data on Non-Wood Plant Fibers. Pulp and Paper Manufacture, Vol. 1: Properties of Fibrous Raw Materials and their Preparation for Pulping

Tissue 360° Forum at PaperCon 2013

“Extraneous Materials”

- Wood is a remarkably clean raw material, once bark has been removed
- Is mostly cellulose hemicellulose, and lignin; small bit of parenchyma and ash (metals)
- Many agricultural residues have a high content of other materials

“Extraneous Materials”

- Parenchyma/pith – large, barrel-shaped cells for storage of food and water
  - Devour alkali during pulping
  - Greatly inhibit pulp drainage
- Fines – either inherent or produced during processing; inhibit pulp drainage

“Extraneous Materials”

- Ash – metals content; can interfere with bleaching and papermaking chemicals
- Silica – almost negligible in wood…can be up to 20 % or more in cereal straws; rapidly fouls heat transfer and other equipment
- Trash/debris/sand – picked up from field during collection

Fiber Crops

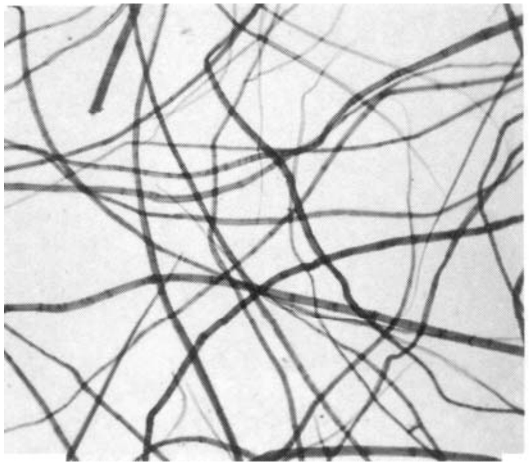
Fiber Crops

- Crops grown specifically to produce fiber for papermaking or other purposes (although other byproducts may be involved)
  - Kenaf
  - Industrial hemp
  - Bamboo
  - Giant Reed

Kenaf

Industrial Hemp

Giant Reed



Kenaf bast fibers

Southern pine fibers

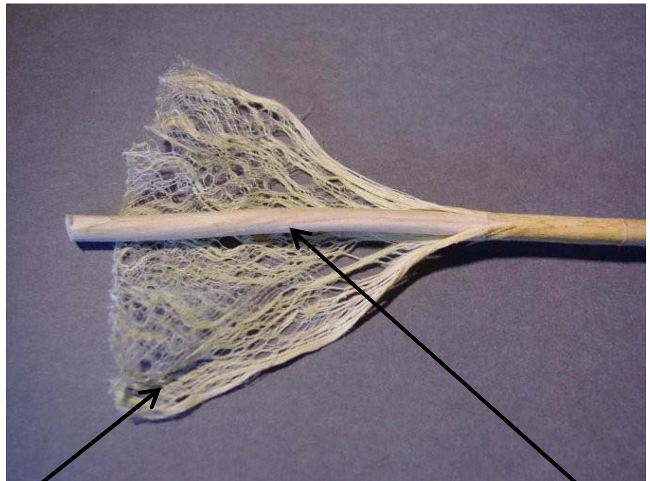
Atchison, J. E. 1983. Data on Non-Wood Plant Fibers. Pulp and Paper Manufacture, Vol. 1: Properties of Fibrous Raw Materials and their Preparation for Pulping

Advantages

- Fiber properties tend to be better than for agricultural residues
- Some materials may have a better combination of properties, compared to wood
- Lower content of “extraneous materials” compared to residues
- Some are woody in nature, meaning that existing wood processing equipment can be used

Possible Problems

- Since there is no principal crop associated with them, fiber crops must have high yield / low cost in order to be competitive vs wood
- Some plants (kenaf, hemp) have two very different fiber types in the core and the bast; how to separate and/or process?
- Others (bamboo, reed) have higher content of ash and silica compared to wood



Kenaf bast

Kenaf core

Possible Nonwood Replacements for NBSK

Requirements: Long-Fiber Fraction for Tissue

- Fiber length sufficient to impart strength and runnability
- Low coarseness/wall thickness to maintain softness
- Fiber crops offer more promise than ag residues

Material	Coarseness, mg/100 m	Avg. Fiber Length, mm
Northern Softwood Kraft (NSWK or NBSK)	**14.2**	**2.92**
Southern Softwood Kraft (SSWK)	26.7	3.46
West Coast Softwood Kraft (WCSK)	23.2	3.38
Northern Hardwood Kraft (NHWK or NBHK)	11.0	1.02
Eucalyptus	7.6	0.99
Abaca	17.4	3.65
Industrial Hemp	13.8	3.36
Sisal	14.0	2.45
Yucca elata	6.7	1.89
Hesperaloe changii	9.0	4.58
Hesperaloe funifera	8.0	2.96

Reeves et al., US Patent 5.320,710

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Already shown to produce high-quality tissue (US Patent 5,320, 710)

Tissue 360° Forum at PaperCon 2013

Material	Comments
Abaca	• Very high strength • Expensive (4-5 times wood pulp) • Limited raw material and market availability
Bamboo	• Over 1250 species • Some with fiber length similar to NBSK • Can be processed in wood pulp mill • Can economically establish bamboo farms
Industrial hemp bast	• High strength • Expensive (3 times wood pulp) • Limited raw material and market pulp availability • Illegal to grow in most of USA
Hesperaloe funifera	• High strength – similar to or better than NBSK • US Patent 5,320,710 “Soft high strength tissue using long-low coarseness hesperaloe fibers” – James River 1994 • Limited raw material availability • Could be cultivated in Mexico on marginal land
Kenaf bast	• Strength similar to NBSK • Expensive pulp due to decortication • Limited raw material availability • Annual crop
Sisal	• High strength • Very expensive (3 times wood pulp) • Limited raw material and market pulp availability

Source: HurterConsult

Possible Nonwood Replacements for BEK

Requirements: Short-Fiber Fraction for Tissue

- Must have a unique combination of properties
  - Moderate fiber length
  - High slenderness
  - Low coarseness
  - Optimum “fiber count”

	Length, mm			Diameter, microns			L/D Ratio
	Max.	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	
Arundo donax			1.18			15	78:1
Bagasse	2.8	0.8	1.7	34	10	20	85:1
Bamboo	3.5 - 9.0	0.38 -2.5	1.36 -4.0	25 - 55	3 - 18	8 - 30	135 - 175:1
Corn stalks	2.8	0.68	1.26	20	10	16	75 :1
Sorghum stalks			1.65	80	30	47	35 :1
Wheat straw	3.1	0.7	1.5	24	7	13	110:1
Hardwood	1.8	1.0	1.2	50	20	25	50:1

Source: HurterConsult

Material	Comments
Arundo donax (giant reed)	• Can be processed in wood pulp mill • Can economically establish Arundo farms • Considered an invasive species in US
Sugar cane bagasse	• Requires depithing (about 32% pith cells) • Competes as a fuel source
Bamboo	• Over 1250 species • Some with fiber length similar to BEK • Can be processed in wood pulp mill • Can economically establish bamboo farms
Corn stalks	• Very large volume available in USA; agricultural residue • Reasonable delivered cost • Contains 18 – 22% pith cells; depithing required • Harvested in 6 – 8 weeks and needs to be stored until use
Sorghum stalks	• Moderately large volume available in USA; agricultural residue • Contains pith cells; depithing required • Harvested in 6 – 8 weeks and needs to be stored until use
Wheat straw	• Large volume available in the USA; agricultural residue • Silica content may be a problem; new desilication processes available • Harvested in 6-8 weeks and needs to be stored until use

Source: HurterConsult

Bamboo –
Growing Interest in the US

Why Bamboo?

- Wide variety of species available worldwide (over 1250)
- Fiber properties can vary from softwood-like to hardwood-like
- Some species can be grown successfully in the US
- Bulk density similar to wood; can be processed in wood mill equipment or co-cooked with wood chips
- Farmers are expressing interest in planting it
  - 3 years until harvest, as opposed to 20-30 years for wood
  - Produces both a food crop (shoots) as well as fiber crop (stem)
  - Harvested annually for 20-35 years before dying
  - Can be managed using well-known methods
- Public announcements by well-known companies about their intent to use bamboo!

Species	Avg. Length, mm	Avg. Width, microns	Avg. Lumen Width, microns	Avg. Cell Wall Thickness, microns
Eucalyptus	0.7 – 1.3	20-30	---	---
Bambusa arundinaria	1.73	22	6	8
Bambusa blummeana	2.02	18	4	7
Bambusa vulgaris	2.33	17	4	7
Gigantochloa aspera	3.78	19	7	6
Phyllostachus bambusoides	0.64 – 1.64	8.9 - 21	---	---
Phyllostachys nigra	1.86	19	6	6.5
Schizostachyum lima	1.67	22	4	9
Schizostachyum lumampao	2.42	14	6	4

Bhargava, R. L., “Bamboo” in Pulp & Paper Manufacture, Vol. 3

	Bambusa arundinacea (Dowga)	**Dendrocalamus strictus (Medar)**	**Monostigma oxygenanthera (Chiva)**	**Eucalpytus**
Hot water solubility, %	6.5	5.8	4.9	7
Alcohol-benzene solubility, %	5.5	4.3	2.9	4
1 % NaOH solubility, %	24.9	24.0	25.4	16
Lignin, %	24.6	26.6	27.5	22
Pentosans, %	17.2	17.7	17.5	14
Holocellulose, %	68.8	67.3	72.0	72
Ash, %	2.7	4.1	3.9	0.2
Silica, %	1.9	2.5	2.3	negl.

US Forest Products Lab Data

Challenges: Using Nonwoods

Nonwood Challenges

- Raw material availability
- Variability
- Extraneous materials
- Finding someone to supply pulp

Raw Material Availability

- For agricultural residues, this is not an issue; they are already present
- For some fiber crops (kenaf, reed, bamboo), they are not currently grown in large quantities
  - Who gets farmers to commit?
  - How long to establish crop?
  - What will price be? How will it fluctuate?

Raw Material Availability

- Are raw materials available close to the pulping site? Can't afford to transport many bulky materials more than 150 miles
- ***What happens if crop fails???***

Variability

- Annual crops have a much higher degree of variability (chemically and physically) than wood
- Fiber quality affected greatly by soil, water, climate
- Can products tolerate such variability?

Extraneous Materials

- Types discussed previously
- Pith and parenchyma consume pulping and bleaching chemicals and greatly reduce slurry drainage
- Ash (metals) can affect processing
- Silica can rapidly foul pulping and chemical recovery equipment

Finding Someone to Pulp

- Most large pulp manufacturers are not willing to make small quantities of pulp from nonwood raw materials
- There are only a handful of mills in the US (about 7) that pulp nonwoods; most of these have little production capacity to spare for a second raw material

Finding Someone to Pulp

- Bulky materials like straw cannot be processed in traditional wood-based pulping equipment; requires specialized batch or continuous equipment
- Ash- and silica-rich black liquors are hard to accommodate in evaporators and boilers designed for wood-based liquor; rapid fouling

Finding Someone to Pulp

- It is highly unlikely that someone would build a new “mini-mill” to pulp a nonwood material
  - Capital cost = $1 million/ton-day minimum
  - Capital costs and raw material transport limit mill size to 50-250 tons/day; this makes resulting pulp prices high compared to wood pulp

Summary: Nonwoods for Tissue Manufacture

Summary: Nonwoods for Tissue Manufacture

- Currently, premium tissue grades produced in the US rely primarily on imported pulp, since domestic wood sources cannot produce the desired properties
- US manufacturers are interested in finding alternatives to imports; nonwoods may offer promise in this regard
- Selected agricultural residues and some fiber crops may be suitable as substitutes for eucalyptus
- Selected fiber crops may be suitable as substitutes for northern softwood kraft
- Bamboo is receiving a lot of interest in the US and may offer properties that make it a suitable replacement for both fiber types
- Nonwoods of all kinds offer challenges not associated with wood