Agricultural Residues and Other Nonwood Plant Fibers

Potentially important renewable resources in the developing world are discussed.

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Many of the developing nations of the world, as well as some of the highly industrialized countries, do not have adequate supplies of wood nor the available land for increasing their wood supplies. However, many of these same countries do have large quantities of fibrous agricultural residues and other nonwood plant fibers which represent another renewable source. Many of these fibers can be used for the same purposes as wood, especially for manufacture of pulps, paper, paperboard, and reconstituted panelboards. They can also be used for production of chemicals and as fuel for generation of steam and power.

The economic use of these important renewable resources has been neglected in most countries in the past. However, as their value becomes increasingly recognized for a multiplicity of uses, they represent a substantial potential source of renewable raw material for the future.

As an indication of the huge requirements for renewable fibrous resources for pulp and paper alone, predictions of the amount of paper and paperboard consumed in future years are summarized in Fig. 1. Knowledge of the present world situation on all raw materials suitable for pulp indicates that the upper limits of the range of anticipated possible consumption levels will never be reached, unless there is a complete breakthrough in finding an inexpensive and limitless source of power and unless a crash program is begun immediately in all areas of the world to develop forests and crops capable of producing enough fiber by that time.

Even with all new measures to increase the availability of wood we cannot afford to neglect other fibrous sources such as recycled wastepaper and greater utilization of the renewable nonwood plant fibers. The continuing downward trend in wastepaper recycling, reaching the level of about 20 percent of the overall fibrous furnish for paper and paperboard in the United States in 1969, could be reversed to meet goals of 25 to 27 percent by 1985, 30 percent by 1990, and up to at least 35 percent by the end of the century. Some countries have already achieved a use rate of 35 percent wastepaper in the overall papermaking furnish (*1*). However, this will not eliminate the critical need for ever-increasing amounts of virgin fibrous raw materials for pulp and paper, including the use of agricultural residues and other nonwood plant fibers.

Present and Potential Use of Nonwood Plant Fibers Worldwide

Although the nonwood plant fibers are used now to only a limited extent in North America and Europe, they represent one of the major sources of fibrous raw material for many of the developing countries of the world. Their importance promises to become greater to many of the developed countries as well, and the pulp and paper industry worldwide should become familiar with the merits of some of these fibers.

These fibers include:

1) Agricultural residues such as sugar cane bagasse, cereal straw, sorghum, and rice straw.

2) Natural growing plants such as bamboo, reeds, papyrus, esparto grass, and other grasses, any of which might also be grown as crop fibers.

3) Nonwood crop fibers which are grown primarily for their fiber content. This last group includes (i) bast fibers or stem fibers, including jute, hemp, kenaf, ramie, crotalaria (or sunn hemp), okra, flax tow, and old rope or rags made from such fibers; (ii) leaf fibers such as abaca (manila hemp), sisal, and henequen; and (iii) cotton fibers, cotton linters, and cotton rags.

Although these nonwood fibers now constitute only about 5 percent of the raw material used for pulp and paper on a worldwide basis, and only about 1 percent in North America, they are particularly important for the developing countries in the Middle East, Asia, parts of Africa, and Latin America. In these areas, the output of nonwood plant fiber pulp has actually been increasing faster than the output of wood pulp. In some countries, and even entire regions, nonwood pulps represent more than 50 percent of the overall fibrous furnish for paper and paperboard.

At the 1973 Nonwood Plant Fibers Conference of the Technical Association of the Pulp and Paper Industry (TAPPI), Atchison (*2*) presented a detailed worldwide review of the present status and future potential for these raw materials. An up-to-date summary of the pertinent statistics and information relative to their use is included herein.

Present and Potential Use of Sugar Cane Bagasse

Of the many nonwood fibers considered or utilized for pulp manufacture, bagasse, more than any other, promises to become the first major fibrous raw material. It is readily available and easily accessible in many countries and, fortunately, is abundant in some wood-poor countries.

From the standpoint of practicality, bagasse is by far the most important nonwood plant fiber. This is easy to understand, since before its use as a fiber source it has already been used to produce 5 to 10 metric tons of sugar per hectare (2.2 to 4.5 short tons per acre). This has carried the rent of land and the costs of growing, harvesting, transporting, and processing the cane. Relatively little additional preparation—only moist and wet depithing—is required before it is ready for the pulp digester. And it is readily available to the pulp mill at the sugar mill conveyor at a cost only slightly higher than that of replacing the bagasse in the sugar mill boilers with fossil fuel. None of the other nonwood plant fibers matches its economic advantages.

During the past 25 years, technical and operating progress in bagasse pulping has been very rapid; it now equals that for wood pulp mills. There are now no technical or operating problems to prevent a rapid expansion in the use of bagasse for pulp. The major economic problem is the cost of fossil fuel to replace the bagasse now used for fuel at the sugar mill and the extra fuel needed for pulp manufacture as compared with that for wood pulp. The other fuel would have to be imported by some coun-

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tries. But this factor will diminish in importance as pulpwood and wood residue costs increase all over the world; this will be true particularly if the countries with bagasse would otherwise have to import pulp and paper at high prices corresponding to those for oil. Also, the manufacture of paper from pulp from local bagasse and imported long-fibered pulp and fuel is generally favorable for the consuming country. This results in a reduction of foreign exchange paid out and provides local employment of capital, labor, and other resources, usually at a lower total cost for the product than for imported paper.

It was not until 1939 that the first three successful bagasse pulp mills began operations: one in Peru, one in Taiwan, and one in the Philippines. Progress at first was very slow, and by 1950 there were still only five or six mills in the world based on utilizing bagasse, with a total production capacity of less than 100,000 metric tons. By 1968, total bagasse pulp production had increased to about 500,000 metric tons, and in 1973 bagasse pulp production exceeded 1 million metric tons. This appears small in comparison to production of wood pulp, which was about 113 million metric tons in 1973, or the total production of pulp including nonwood plant fiber pulp, amounting to 120 million metric tons in 1973. However, on a percentage basis the use of bagasse as a raw material for pulp and paper has increased more since 1950 than the use of any other fibrous raw material.

At the present time, there are more than 30 bagasse pulp mills with daily capacity of more than 30 metric tons. For many of these, daily capacity is in the range of 100 to 150 metric tons, and for some is as high as 250 metric tons. In addition, there are at least 50 small bagasse pulp mills with daily capacity of 10 to 25 metric tons. Altogether, bagasse pulp is produced in 22 countries. At the present time one new bleached market pulp mill for production of 300 metric tons per day is under construction in Taiwan, and a bagasse newsprint mill for production of 300 metric tons per day is under construction in Peru. Many other large mills with capacity of 200 to 350 metric tons per day are being planned or considered all over the world, primarily in the wood-poor countries.

A wide range of types of bagasse pulp are now produced. These vary from the mechanical type pulp of very high yield, used for insulation board, to the highest quality, high-brightness bleached bagasse pulp used for high quality tissue, printing, and writing papers and bleached paperboard.

Bagasse pulps are now used in practically all grades of paper, including bag, wrapping, printing, writing, toilet tissue, toweling, glassine, corrugating medium, linerboard, bleached boards, and coating base stock. Sugar cane bagasse has great potential for the future as a renewable fibrous resource.

Present and Potential Use of Cereal Straws and Rice Straw

Straw is the most abundant of all of the nonwood plant materials. Great quantities of this renewable resource are available all over the world. Prior to World War II, there were a number of strawboard mills in the U.S. Midwest. However, these have either closed or have switched over to wastepaper or semichemical hardwood pulp for corrugating medium and to wastepaper for combination board. The changing agricultural pattern, with wheat being grown farther west, greatly increased the collection area and the transportation costs to the existing mills. The use of straw became uneconomical, and wastepaper and low-cost hardwoods were substituted as raw material.

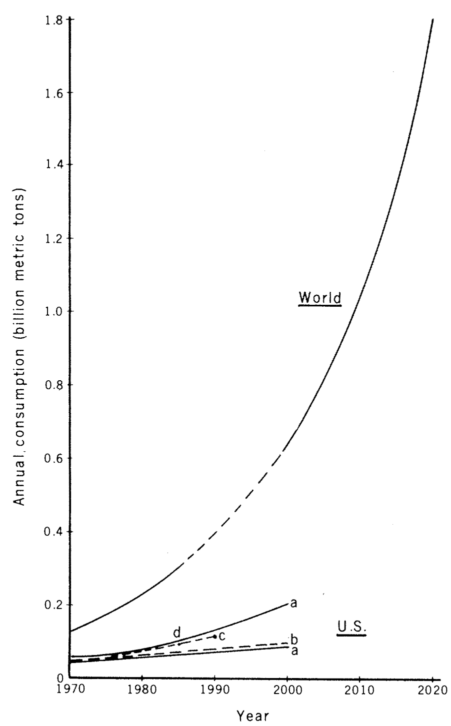

Fig. 1. Predictions for U.S. and world future annual consumption of paper and paperboard. Sources for predictions are as follows: United States: (curve a) Resources for the Future, Inc., Washington, D.C.; (curve b) *U.S. Forest Resource Report No. 17* (Department of Agriculture, Washington, D.C., 1965); (curve c) B. Slatin, *Tappi* **55**, 499 (1972); (curve d) D. Hare, in *U.S. Forest Resource Report No. 18* (Department of Agriculture, Washington, D.C., 1967). World Projections: 1970–1985, U.N. Food and Agricultural Organization (1971); 2000–2020, *Papir a Celuloza* (1972). In 2020 world average use is estimated at 182 kilograms per capita per year.

It is still economical or of national interest, however, to use cereal straw and rice straw in many other countries. They are now being used in 35 countries for production of pulp, and several new large straw mills are being built. Total production of straw pulp on a worldwide basis has remained relatively constant at about 1.36 million metric tons (1.5 million short tons) annually. However, with changing economic conditions a further increase in the use of straw is predicted.

By using better collection methods, the total worldwide straw potential could exceed 1 billion metric tons, of which 100 million metric tons might be collected in the United States alone. Even if 10 percent of the world's straw were used for pulp production, this could mean more than 30 million metric tons of pulp worldwide and more than 3 million metric tons in the United States alone. Greater use of this resource awaits only the economic necessity.

If there is to be any substantial increase in the use of straw in the United States, greater efforts must be made to develop more economical methods for straw collection, handling, transportation, and storage, so that the price of straw to the mill will be more competitive with that of other raw materials such as hardwoods. If strenuous efforts are made in this direction, straw may once again find use in the centers of the wheat-growing areas such as the Dakotas, Kansas, and Nebraska.

Great changes in collection, handling, and storage methods are probably possible along the lines of bulk storage of bagasse and bulk handling and storage of chips. By completely eliminating the baling of straw and handling it entirely in bulk, it is believed that costs might be decreased drastically. Now may be the time to get started on a project toward greater utilization of this valuable resource, which is renewed annually.

Use of Bamboo

Bamboo was first utilized for papermaking in China centuries ago by crude extraction methods. It is still one of the major fibrous raw materials of the People's Republic of China, with bamboo production estimated at 550,000 metric tons in 1972.

Modern-day interest in bamboo utilization appeared in India 55 years ago, and commercial application started about 45 years ago. The world's modern bamboo pulp and paper industry is still centered in India, where 70 percent of the total pulp produced is made from bamboo in about 20 mills. Total bamboo pulp production in India in 1972 is estimated at 550,000 metric tons.

Table 1. Estimated world capacities and production of paper and paperboard compared to estimated capacities and production of nonwood plant fiber pulps in 1972; ADMT, air-dry metric tons.

Area	Paper and paperboard production capacity* (1000 ADMT)	Paper and paperboard production† (1000 ADMT)	Paper-grade nonwood plant fiber pulp production capacity* (1000 ADMT)	Paper-grade nonwood plant fiber pulp production† (1000 ADMT)	Nonwood plant fiber pulp in overall furnish† (%)
North America	66,027	59,424	1,000	450	0.8
Latin America	4,947	4,452	639	575	12.9
Western Europe	41,246	37,121	1,148	1,030	2.8
Eastern Europe	5,099	4,589	251	225	4.9
U.S.S.R.	9,800	8,820	850	480	5.4
Africa	1,144	1,029	160	131	12.7
Near, Middle East	567	510	67	50	9.8
Japan	15,609	14,048	6	6	
People's Republic of China	4,450	4,005	2,400	1,900	47.4
Asia, Far East	2,963	2,667	1,326	1,190	44.6
Oceania	1,855	1,670	3	3	0.2
World total	153,707	138,335	7,850	6,040*‡	4.4

*Estimates by U.N. Food and Agricultural Organization. †Estimates by Joseph E. Atchison Consultants, Inc., based on production data from many sources. ‡In addition to the paper grade pulp, about 270,000 ADMT of dissolving grade pulp is manufactured from cotton linters, making a total of 6,310,000 ADMT of nonwood fiber pulp.

Small bamboo pulping installations also exist in Burma, Thailand, Pakistan, Indonesia, Bangladesh, Taiwan, the Philippines, and Brazil. Additional mills are being considered in other countries such as Burma and certain areas of Africa, where there are tremendous unexploited stands of bamboo. It is estimated that the total world-wide production of bamboo pulp in 1972 was about 1,360,000 metric tons, including that of the People's Republic of China.

The properties of bamboo kraft pulp—relatively high tear but low tensile strength—make it particularly suitable in blends with pulps of lower tear but higher tensile strength, such as those from hardwood and bagasse; the blends provide a useful balance of strength and other properties for many grades of paper.

Unfortunately, entire native bamboo stands have a tendency to flower unexpectedly, seed, and die. As several years are required to reestablish the bamboo stand, any mill relying on bamboo must choose plantation species with the longest period of preflowering maturity. However, a gradual increase in the use of bamboo as a source of pulp, is believed likely, especially in the developing countries where it will be grown as a crop fiber.

Reeds as Raw Material for Pulp

Huge quantities of reeds grow in the saltwater delta areas of many rivers in eastern Europe, Africa, and Asia. The major reed (*Phragmites communis*) grows stalks 3 to 4.5 meters high and 2.5 centimeters in diameter. It has had only limited use for pulp until recently, because of the problems of harvesting the stalks.

In view of the vast quantities of this raw material available annually and its suitability for a soft and bulky pulp for printing papers, improved and less costly collecting and harvesting procedures will probably bring about increased utilization in future years.

An extensive experimental program is presently under way in southern France on the cultivation of another reed—*Arundo donax*—in large plantations to supplement the limited supply of hardwoods in a region with existing pulp mills.

Papyrus as a Pulp Source

In ancient times papyrus paper was made in Egypt from the pith of the paper reed (*Cyperus papyrus*) growing in the shallow waters of the Nile River. The rind of the stalk, which actually contains the good papermaking fiber, was removed from the core of pith. The core was then sliced into thin strips, which were laid parallel in crossing layers under a cloth and pounded with a mallet into a unified sheet. Drying the sheet in the sun caused the pith cells to collapse and the layers to stick together. After that the surface was smoothed with a polished stone, and scrolls were formed by joining several sheets end to end. This product was used in and exported from Egypt from the 5th century B.C. to the 4th century A.D., when it was replaced with parchment.

At the present time papyrus grows in the lakes and rivers of many areas of Africa, the Middle East, and South America. Huge quantities can be found in the upper Sudan, where a number of promotional efforts have been made over the years to develop a paper industry based on the raw material. One mill was built on the upper Nile before World War II, but it was not successful and was abandoned.

Papyrus is somewhat similar to bagasse in that it contains about 35 percent pithy material and 65 percent good rind fiber suitable for production of high quality bleached pulp. However, the technical problems of removing the pith and the economic problems of harvesting the stems in the swamps and transporting raw material containing 90 percent water appear to represent almost prohibitive obstacles to developing a paper industry based on papyrus.

Esparto Grass and Sabai Grass

Esparto grass grows in the wild state over fairly extensive areas in North Africa and also in southern Spain near Almería. The plant occurs as a coarse, strong grass which is actually a long, rolled-up leaf in a sheath. It grows to 1 meter in height in clumps of 0.3 to 0.6 meter in diameter. The grass is harvested by hand pulling so as to leave the root intact for regrowth. The grass is harvested over a 4- to 6-month period between August and April.

Esparto grass has been used for production of high quality bleached pulp for more than 100 years, and it has some special properties such as high opacity, good bulk, excellent dimensional stability, and good printability. There are esparto pulp mills in France, Spain, Algeria, and Tunisia, and one is being considered in Morocco. However, the total amount of esparto grass available on an annual basis is only about 500,000 metric tons, so that the maximum potential pulp from the source is only about 200,000 metric tons.

Sabai grass, which has some of the desirable characteristics of esparto, is used to a very limited extent in both India and Pakistan.

Leaf Fibers

The leaf fibers, such as sisal, abaca, and henequen, have found very little use in the pulp and paper industry, except on a small volume for specialty grades. Although the pulp produced from some of these fibers, such as abaca, has outstanding qualities, the cost of growing, harvesting, handling, and pulping these materials is extremely high. Therefore, it appears that their use in the pulp and paper industry will remain very limited.

Use of Kenaf and Other Bast Fibers or Stem Fiber Plants

The bast fibers that are found in bark of the stems of such plants as jute, true hemp, kenaf, ramie, crotalaria (sunn hemp), okra, and roselle have also not found great use in the paper industry because of their high cost. Only the bast fiber has been used, and the core material, representing about 60 to 65 percent of the total dry weight of the stalk, has been discarded.

In recent years, however, kenaf has emerged as a stem plant fiber which appears to have great potential. Much research has been done by the U.S. Department of Agriculture during the past 10 years on both the cultivation of this plant and its utilization for manufacture of pulp and paper.

As a result of the recent shortage of pulp and its extremely high price in the world market in 1973 and 1974, interest in kenaf has spread all over the world. There is no doubt that kenaf and some of the related species of bast fiber plants, such as roselle and crotalaria, will soon find widespread use in the pulp and paper industry.

Here again, some concentrated well-financed efforts will have to be devoted to the problems of harvesting, handling, storing, and processing the kenaf stalk before it or its two components, long and short fiber, go to the digester. However, when it is considered that growth rates of 15 to 25 metric tons of dry stalk material per hectare (6 to 10 short tons per acre) have been achieved in good growth areas, this renewable resource certainly merits the continued concentrated efforts required to make its use a commercial reality.

Present Production of Pulp from Nonwood Plant Fibers

To put the importance of the nonwood pulp into proper perspective, consider the U.N. Food and Agricultural Organization world capacity estimates for total paper and paperboard for 1972 in the various regions of the world as compared to the capacity estimates for nonwood plant fiber pulp. This comparison gives an indication of the percentage of nonwood fiber pulp used in the furnish in various regions. These data are shown in Table 1 along with estimates of actual production levels in each area for 1972 and the percentage of nonwood fiber pulp used in the furnish in each region.

For the entire Far East and Asia, including the People's Republic of China, nonwood plant fibers play an extremely important role, with the area as a whole using almost 50 percent nonwood fiber pulp in the total furnish. In Latin America, Africa, the Near East, and Middle East, the percentage varies from 9.8 to 13.5 percent. By contrast, the use of nonwood plant fibers in Japan and Oceania is almost nil, and in North America they represent less than 1 percent of the total fibrous furnish (Table 1).

For the United States specifically, an estimate of the total consumption of nonwood plant fiber pulp for paper and board, including high-yield bagasse pulp for insulating board, is given in Table 2. In addition to the nonwood fiber pulp produced for papermaking in the United States, about 130,000 short tons of cotton linter pulp are produced for dissolving pulp, some of which is exported.

Table 2. Estimated total nonwood plant fiber pulp consumption in the United States in 1972 for paper and board

Item	Amount consumed (metric tons)
Bleached bagasse pulp	36,300
High-yield mechanical type bagasse pulp for wallboard	181,500
Cotton linter pulp	45,400
Rag pulp (bleached)	45,400
Flax pulp	36,300
Abaca pulp	14,500
Rag pulp for roofing felt	99,400
Total	453,800

Table 3. Estimates of total production of various nonwood plant fiber pulps in 1972.

Raw material	Estimated world production of pulp (1000 ADMT)	Estimated U.S. production of pulp (1000 ADMT)
Cereal straw, mainly wheat and rye	1,360	
Rice straw	630	
Bamboo	1,360	
Bagasse	915	218*
Reeds	270	
Cotton linters, both paper grade and dissolving pulp	330†	160†
Esparto and sabai grass	110	
Rags, abaca, flaxseed straw, hemp, sisal, and other nonwood plant fibers	1,335	187
Estimated total nonwood plant fiber pulp production	6,310	565

*U.S. bagasse pulp production includes high-yield pulp for wet process insulating board production. †U.S. cotton linter pulp production includes 115,000 ADMT for dissolving pulp and 45,000 ADMT for papermaking. World cotton linter pulp production includes about 270,000 ADMT for dissolving pulp and 60,000 ADMT for paper grade pulp.

Nonwood plant fibers are presently playing a very minor role in North America. In fact, there has been practically no increase in their use over the past 10 years. This has also been true of Europe, Japan, and Oceania. However, in the case of Latin America, the use of nonwood plant fiber pulp has approximately doubled in the past 10 years. In Africa, the Near East, and Middle East, it has approximately tripled between 1962 and 1972, and in the Far East excluding Japan, the increase for the 10-year period has been on the order of 70 percent, or an annual average of 5.5 percent compounded annually.

Table 3 shows an estimate of the total production of each of the nonwood plant fiber pulps in 1972, both on a worldwide basis and for the United States separately. It can be seen that straw, bamboo, and bagasse are the leading nonwood plant fibers now in use.

Yields of fiber per hectare for nonwood plant fibers used in papermaking are given in Table 4, along with the estimated equivalent amounts of bleached pulps that could be produced from them.

Total Worldwide Availability of Nonwood Fibrous Raw Materials

From data the total worldwide production of agricultural crops and the acreage planted in each crop, it is possible to make reasonably accurate estimates of the total amount of each type of residual fiber that might be collected in each country. Similarly, for fibrous crops that are grown specifically for the fiber content, it is possible to make accurate estimates of total availability. However, in the case of wild-growing raw materials such as reeds and bamboo, such estimates are far more difficult, and accurate data are not available.

The estimates in Table 5 give a reasonably good indication of the tremendous quantities of these nonwood plant fibers which can become available if they should be needed as raw materials in papermaking. The estimated total exceeds 1 billion metric tons of fibrous raw material, of which only a small fraction is being used.

Straw has the greatest overall potential if only quantity is considered. Furthermore, this potential can easily be increased to more than 1 billion metric tons if efficient and economic bulk handling and storage methods are developed.

From an economic standpoint, however, it is believed that bagasse will continue to lead all other nonwood plant fibers for the medium-term future. It promises to become a major papermaking pulp during the 1970's and 1980's, and may represent 2 to 3 percent or more of the world pulp production of 220 million metric tons expected by 1985, as compared to less than 1 percent of world production at the present time. By 1985, it is expected that total nonwood plant fiber pulp production will amount to 7 or 8 percent of total world pulp production as compared to less than 5 percent at present.

To summarize the nonwood plant fiber picture, there is no doubt that the nonwood plant fibers will play an increasing role in the world's pulp and paper industry. It appears that the necessary fibrous resources either exist already or can be grown in the developing countries to sustain the increasing pulp and paper requirements in these areas. Furthermore, some of these areas will become net exporters of nonwood pulp, especially bagasse pulp, even to the highly developed countries such as Japan and Western Europe.

Conclusions About Future Use of Nonwood Fibers

The world's pulp and paper industry, as well as the forest products industry in general, is becoming more and more concerned about its future sources of fibrous raw material. Already we see massive movement of pulpwood chips over long distances by sea, and this practice will undoubtedly expand greatly in future years. Many large-scale plantations of fast-growing pine and hardwoods in the tropical areas are being developed. Some giant projects in Brazil for growing eucalyptus have already gotten under way.

The mixed tropical hardwoods are also being considered seriously as a raw material for pulp and paper. Some mills are already using these woods successfully for a variety of paper and paperboard products ranging from newsprint to linerboard. Other large-scale projects based on mixed tropical woods are under development.

There appears to be no question that nonwood fibers will play an increasing role in satisfying the world requirements for fibrous raw material. More than 1 billion metric tons of such material could be made available, and even greater quantities could be grown if necessary.

By properly selecting the appropriate mixture of nonwood fibers, and the appropriate pulping processes, any grade of paper and paperboard can be produced. If circumstances require, all grades can be produced without the addition of any wood pulp. In fact, some grades are already being produced with 100 percent nonwood fibers. However, in most cases, it is expected that nonwood fibers will be used in blends with at least a small proportion of wood pulp.

Bagasse will undoubtedly be in the forefront, as it has been over the past 18 years. Already, several large bleached bagasse market pulp mills for production of high-brightness pulp are either under construction or in advanced planning stages. These include a bleached bagasse market pulp mill in Peru with capacity of 350 bone-dry metric tons (BDMT), which is being developed by Industriás del Peru, and a 300-BDMT-per-day bleached bagasse market pulp mill in Taiwan being constructed by Taiwan Sugar Corporation.

Other large bagasse market pulp mills are being considered in the Philippines, Australia, Mexico, Peru, Hawaii, the Caribbean area, and South Africa. In addition, many expansion programs are under way at existing bagasse pulp and paper mills all over the world, and many new integrated projects are either under construction or are being seriously considered, including bagasse newsprint projects, each with capacity of 300 ton/day, in Peru and Mexico and a 300 ton/day integrated bleached bagasse pulp and paper mill in Cuba.

Furthermore, large-scale expansion programs are being developed for utilization of bagasse for production of fiberboard and particleboard, including three projects in Cuba, each with production capacity of 100 ton/day.

It seems almost inevitable that straw, with its enormous supply potential will eventually reemerge as a major raw material, whether for pulp, chemicals, or even fuel. Potential economic advantages of its use will sooner or later lead to the required development work on collection and storage. Just recently, contracts have been signed for a 120 ton/day bleached straw pulp and paper mill in Syria and a 200 ton/day mill in Turkey. Kenaf and other straw fibers also have great potential for the future as the remaining problems are gradually solved.

Table 4. Estimated annual collectable yields of various nonwood plant fibrous raw materials per hectare; BDMT, bone-dry metric tons.

Raw material	Estimated collectable fibrous raw material (BDMT per hectare)	Estimated equivalent in bleached pulp (BDMT per hectare)
Sugar cane bagasse	5.0 –12.4	1.7 –4.2
Wheat straw	2.2 – 3.0	0.7 –1.0
Rice straw	1.4 – 2.0	0.4 –0.6
Barley straw	1.4 – 1.5	0.4 –0.5
Oat straw	1.4 – 1.5	0.4 –0.5
Rye straw	2.5 – 3.5	0.8 –1.0
Bamboo, natural growth	1.5 – 2.0	0.6 –0.8
Bamboo, cultivated	2.5 – 5.0	1.0 –2.1
Reeds, U.S.S.R.	5.0 – 9.9	2.0 –4.0
Kenaf, total stem weight	7.4 –24.7	3.0 –9.9
Kenaf bast fiber	1.5 – 6.2	0.7 –3.2
Crotalaria bast fiber	1.5 – 5.0	0.7 –2.5
Papyrus, upper Sudan	20.0 –24.7	5.9 –7.4
Abaca (manila hemp) fiber	0.7 – 1.5	0.4 –0.7
Flaxseed straw	0.5 – 1.0	0.09 –0.17
Cotton staple fiber	0.3 – 0.9	0.25 –0.86
Second-cut cotton linters	0.02– 0.07	0.015–0.062

Table 5. Estimated availability of specific nonwood plant fibrous raw materials, 1972. Values are for potential availability with present collection methods.

Raw material	World-wide (1000 BDMT)	Continental U.S. (1000 BDMT)
Sugar cane bagasse	55,000	1,600
Wheat straw	550,000	50,000
Rice straw	180,000	1,000
Oat straw	50,000	8,000
Barley straw	40,000	5,000
Rye straw	60,000	2,000
Flaxseed straw	2,000	500
Grass seed straw	3,000	1,000
Subtotal, straw	885,000	67,500
Bast fibers		
Jute, mainly from India and Bangladesh	4,425	
Kenaf and roselle, mainly from India and Thailand	1,674	
Subtotal, bast fibers	6,099	
Leaf fibers		
Sisal	648	
Abaca	92	
Henequen	164	
Subtotal leaf fibers	904	
Reeds	30,000	
Bamboo	30,000	
Papyrus	5,000	
Esparto grass	500	
Sabai grass	200	
Total, cotton staple fiber	13,500	3,000
Total, second-cut cotton linters	1,000	250
Estimated total	1,027,203	72,350

References

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2. J. E. Atchison, *TAPPI CA Rep. 52* (1973), progress rep. No. 4, pp. 69–89.