ENVIRONMENTAL FOOTPRINT COMPARISON TOOL

A tool for understanding environmental decisions related to the pulp and paper industry

EFFECTS OF NON-WOOD FIBER USE

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OVERVIEW OF EFFECTS OF NON-WOOD FIBER USE

Introduction

There is currently little environmental or economic impetus for wider use of agricultural crops and crop residues for the manufacture of paper products in North America. Research by Bowyer, who has extensively evaluated opportunities for using agricultural fiber as a papermaking raw material, provides the following conclusions that sum up the situation.

- *When environmental attributes of kenaf and wood fiber are compared, the yield advantage of kenaf, and thus, lesser land requirements to produce a given amount of pulp, appears to be overwhelmed by the highly intensive nature of activity on the land that is in production. Thus, among the factors that favor production of kenaf fiber for use in papermaking rather than wood, environmental protection is not one of them* (Bowyer 1997).
- *Examination of the total environmental impacts of papermaking fiber production in forest plantations versus fiber production using agricultural crops shows significant advantages to wood fiber* (Bowyer 2001).

Circumstances in the developing world, however, are economically more favorable for non-wood fiber use and continue to prompt technological research and development to improve manufacturing processes related to non-wood fiber. In the past, paper producers in North America have explored and will continue to explore opportunities to reduce costs or improve fiber quality by using non-wood fibers in specific mills and product lines.

What options exist for the use of agricultural fiber?

Potential sources of non-wood fiber that have been considered for papermaking in North America include

- *dedicated annual crops* grown specifically for fiber, such as kenaf, jute, flax, and hemp. In extensive studies the USDA found kenaf to be the most promising annual fiber crop (Kugler 1990; Taylor 1993), and
- *agricultural residues* remaining from the harvest of food-based crops such as wheat and other cereal straws (barley and oats), rye seed grass, cornstalks, and bagasse from sugar cane.

Wood, agricultural crops, and crop residues are all important sources of papermaking fiber. Choices will be inherently driven by

- relative abundance and delivered costs,
- compatibility with existing manufacturing infrastructure,
- contribution to product characteristics and manufacturing efficiencies,
- environmental objectives, and
- economic viability and success of products in the marketplace.

Why can't the international experience with non-wood fiber be extended to North America?

Globally, the predominant use of non-wood fiber in the manufacture of paper products is concentrated in geographic areas characterized by historically diminished forestlands and wood fiber scarcities. Even in areas where non-wood fiber has historically been the predominant domestic fiber source, wood fiber has been the preferred choice to supply larger, more efficient paper manufacturing equipment now being installed to sustain large and rapid capacity increases (for example, in China).

Effects of Non-Wood Fiber Use

General Overview

At present, non-wood fiber use in North America is largely limited to the manufacture of specialty and niche paper products that command premium prices in the marketplace.

Though there is a body of information to suggest the technical feasibility for using non-wood fiber in a broad array of paper applications, economic evaluations in North America have thus far not favored the construction of mills dedicated to the use of non-wood fiber. This is, in part, attributable to the efficiencies of scale and fiber acquisition advantages related to the manufacture of wood pulp-based products.

What, if any, manufacturing hurdles discourage existing mills from using non-wood fiber?

Use of non-wood fiber would require significant adaptations to mills designed for fiber with distinctly different characteristics, operating at significantly different scales of production. Paper manufacturers with investments in large-scale wood-based technology continue to find wood far easier to source, transport, store, use and plan for than non-wood alternatives (Roundtable 1997).

Non-wood sources of fiber are amenable to the same basic pulping approaches as wood fiber sources. Chemical processes are most common worldwide. Yet the amenability of non-wood fiber sources to conventional pulping processes has not led to significant commercial scale application in North America. A number of barriers have contributed to this state.

- Widespread use of non-wood fiber sources would require a fundamental change in the paper industry’s raw material supply and procurement infrastructure.
- The costs for transportation and storage of low-density non-wood fiber limit mill size and lose the economies of scale enjoyed by wood fiber mills.
- Lower lignin and higher silica contents associated with agricultural residues make conventional chemical recovery systems at wood-based mills inefficient.
- Material handling systems designed for wood, wood chips and wood pulps are not equally well suited for non-wood fiber. Most agricultural fibers are not compatible with the raw material handling and pulping stages of existing wood pulp mills (Kinsella 2004).
- Slower draining short-fibered non-wood fibers such as those associated with wheat straw impair paper machine efficiencies.

Are there environmental advantages related to use of non-wood fiber that would justify manufacturing compromises?

Potential environmental co-benefits and trade-offs associated with the use of alternative fibers include those related to water consumption, use of renewable and fossil fuel energy, the generation of chlorinated compounds, wastewater quality, and emissions of greenhouse gases. In addition, one of the most significant aspects to consider is the relative land impacts of growing non-wood fiber versus wood-based fiber. Differences relate not only to land use patterns, but also to the impacts related to differing agronomic practices associated with alternative crops in terms of energy use and associated atmospheric emissions, water consumption, and the character of land surface runoff. As a generalization, the environmental advantage rests with wood fiber.

How can wood fiber use be justified when paper can be made from otherwise wasted agricultural residue?

Use of agricultural residues for paper production would make use of what would otherwise be a waste material. A similar synergy exists between the lumber industry and manufacturers of wood pulp (McKeever 2004), and thus, both sources of fiber have this co-benefit associated with them. At the root of the forest products industry is the harvesting of timber for production of lumber and other wood products. Sawmills annually generate enormous quantities of bark, wood chips, and other wood residues that are a valuable commodity. Nearly all of these residuals are used to produce other products, primarily paper, nonstructural wood panels, and biofuel (McKeever 1998).

The pulping of wood also yields commodities beyond the fiber used in paper manufacturing. For example, tall oil and turpentine are two versatile products recovered from the wood pulping process that have given impetus to a wood-derived chemicals industry. Once recovered, these chemical feedstocks are used to produce products with numerous industrial and household uses. As the forest products sector embraces technologies that allow for a broader spectrum of co-products (e.g., nanocrystalline cellulose), the compounded value of these additional commodities will increase.

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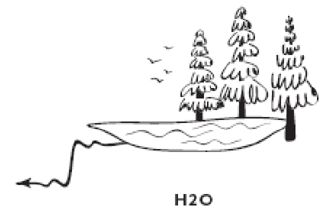


EFFECTS OF NON-WOOD FIBER USE ON WATER USE

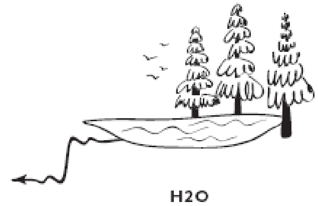
Overview

The use of non-wood fiber for pulp and paper manufacture has different water requirements compared to those for wood-based fiber—both in terms of water used for irrigation, and for water used during the manufacturing process.

More information

Relative irrigation needs

Process water needs



EFFECTS OF NON-WOOD FIBER USE ON WATER USE

Relative Irrigation Needs

Because wood fiber is cultivated over a lengthy rotation, productivity is relatively unaffected by seasonal or annual variations in rainfall. There have been evaluations of very intensive high-yield silviculture where drip irrigation and fertilization have been employed. This is not common silvicultural practice, however.

Intensively grown agricultural fiber crops are less tolerant and more demanding in their water requirements. Kenaf, for instance, requires approximately five inches of water per month. To ensure a reliable fiber supply, irrigation capacity would likely have to be available to compensate for precipitation shortfalls (Bowyer et al. 2004).

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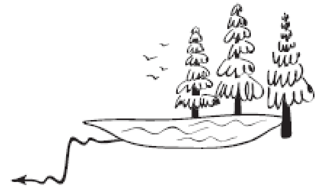

EFFECTS OF NON-WOOD FIBER USE ON WATER USE

Process Water Needs

Commonly cited agricultural fibers, straw and kenaf bring to the paper manufacturing process disproportionate amounts of short fiber. Though this is sometimes an advantage for some grades, the poorer drainage properties of shorter fiber require more dilute fiber furnishes and a commensurate increase in process water requirements. Figure N1 presents effluent flows that correspond with relative water use.

	Kenaf		Softwood
Bleached chemical pulps	Kraft [1]	Soda [2]	Kraft [3]
Effluent flow (gallons per air-dried ton of	36,000	20,000	18,700
Effluent Quality (kg/air-dried metric ton of			
Biochemical oxygen demand	1.5 - 2.3	5.8	0.3 - 6.7
Chemical oxygen demand (COD)	18.0 - 22.5		14.4 - 72.8
Total suspended solids (TSS)	3.0 - 4.5		0.2 - 9.8

Notes:
All three mills have secondary treatment.

[1] The Phoenix mill produces market pulp from wholestalk kenaf. Reported treatment efficiencies are 97% for BOD and TSS and 87% for COD. V. P. Leekha and S.K. Thapar, "Experiences in Kenaf Pulping in Thailand," *TAPPI Proceedings of the 1983 Pulping Conference* (Atlanta: TAPPI Press, 1983) pp. 288-293.

[2] Sandwell Inc, *Kenaf Assessment Study*, draft report prepared for the Tallahatchie Board of Supervisors, Charleston, Mississippi, April 19, 1991, p. 16.

[3] Effluent quantity: See White Paper 10A.
Effluent quality: U.S. EPA, *Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Point Source Category*. Washington: U.S. EPA Office of Water, EPA-821-R-93-019, pp. 6-48 - 49, 10-42.

Figure N1. Relative Effluent Flows and Effluent Quality for Kenaf vs. Softwood Fiber (Source: Paper Task Force 1996)

The potentially greater water demand does not constitute a consumptive use of water, but it could be a constraint in situations where water supplies are limited. Higher process water use requirements associated with agrifiber would impose a greater hydraulic load on wastewater management systems whose costs are sensitive to hydraulic load. Increased water use could also mean a greater loss of heat and process water chemicals that contributes to an incrementally larger life cycle footprint.

Reference

Paper Task Force. 1996. *Non-wood plant fibers as alternative fiber sources for papermaking*. White Paper 13. http://c.environmentalpaper.org/documents/1634_WP13.pdf

ENVIRONMENTAL FOOTPRINT COMPARISON TOOL

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ENERGY

EFFECTS OF NON-WOOD FIBER USE ON ENERGY USE

Overview

The cultivation and harvesting of dedicated agricultural fiber crops requires somewhat larger amounts of fossil fuel relative to wood fiber due to its greater cultivation intensity and significantly greater reliance on fertilizers. While non-wood fiber typically requires less overall manufacturing energy, wood fiber has a significant renewable fuel advantage when chemically pulped.

More Information

Differences in fossil fuel demand

Manufacturing energy

Role of wood-derived fuels

EFFECTS OF NON-WOOD FIBER USE ON ENERGY USE

Differences in Fossil Fuel Demand

The cultivation and harvesting of wood fiber has a significant fossil fuel advantage over dedicated agricultural crops by virtue of the latter's greater requirements for irrigation, fertilization, and field operations associated with planting and harvesting. For the comparisons developed here, agricultural field operations and irrigation represent approximately 60% of the fossil fuel burden for a dedicated fiber crop. The balance is required for the production and distribution of fertilizers necessary to sustain the more intense annual cultivation of agricultural fiber. In contrast, on an acreage basis, the fossil fuel required to cultivate and harvest wood fiber is approximately 20% of that for a dedicated agricultural fiber crop, in the scenario developed below. The differences in energy are driven by the relative extent of fertilization and intensity of cultivation.

Fertilization - Fertilizer production is energy-intensive. As a generalization, 40 to 50% of the energy consumed for agricultural production is associated with the manufacture and distribution of fertilizers. Nitrogen fertilizer in particular is extremely fossil fuel-intensive, requiring about 1.5 pounds of oil equivalents to make 1 pound of fertilizer. According to a study by the Paper Task Force (1996), the embodied fossil fuel energy is the approximate equivalent of 10 gallons of diesel fuel per acre, assuming a 34 pound per acre fertilizer application rate that reportedly maximized yield in University of Mississippi studies (CNN 2008; Helsel 1993).

Where undertaken, forest silvicultural fertilization, over the course of a rotation of 10 to 20 years, *may* reach levels comparable to agricultural practice, though the latter is undertaken each year. Thus, agrifiber fertilization thought necessary to sustain high yields has at least 10 to 20 times greater application rates than those associated with silvicultural practice. Using the University of Mississippi benchmark for kenaf, the Paper Task Force has noted that the embodied fossil fuel energy for these forestlands would be proportionately at least an order of magnitude less than that for agrifiber, on the order of 0.5 to1.0 gallons of diesel fuel per acre (Paper Task Force 1996).

Irrigation - Among food production activities, energy use for irrigation ranks third behind 1) pesticide and fertilizer manufacture and use, and 2) farm energy use. For purposes of a benchmark, a review of irrigation practices among nine midwestern states is instructive (Graboski 2002). In that analysis, the approximate equivalent of about 1.7 gallons of diesel fuel per acre was required to provide 1.0 acre-feet of water.

Planting and Harvesting Estimates - The more intensive land management required for growth of dedicated fiber crops is high in fossil fuel use. Agricultural field operations associated with kenaf cultivation include 1) chisel plowing, 2) disking, 3) double disking with herbicide, 4) pre-planting fertilizer application, 5) bedding, 6) planting, 7) side dressing, and 8) cultivation (Scott and Taylor 1990). Equipment that might be used for harvesting and baling the crop would include a corn silage harvester, boll buggies, and module builders (Bazen, Roberts, and English 2007).

Published information showing fuel use associated with these various agricultural field operations allows an estimate of fuel requirements (Frisby 1993; University of Tennessee 2009). With the caveat that field crop budgets and fuel use may vary widely from farm to farm, fossil fuel required to plant, cultivate, harvest, bale, and collect kenaf is on the order of 12 gallons per acre. The estimate is not an unreasonable one when compared to a published figure showing use of 10.5 gallons of diesel and gasoline for a corn crop (Ryan and Tiffany 1998). Using a crop yield of 6.5 tons kenaf per acre, this translates into a fossil fuel use of about 1.8 gallons per ton of whole stalk kenaf.

As for forest silviculture, fuel requirements have been estimated in one life cycle impact review of forest resource activities that involved a rotation age of 25 years. The corresponding yield was 2.7 tons of wood per acre (Johnson et al. 2005). Fossil fuel requirements from planting through delivery of the wood amounted to 2.7 gallons per ton of wood. The fossil fuel required for growth and harvesting of the wood amounted to about 1.3 gallons per ton. Approximately 85% of that was for fuel and lubricants required for stump-to-truck operations.

Relative fuel intensities depend, of course, on pulp yields of the respective fiber crops. The most favorable case for kenaf involves mechanical pulping of the whole stalk. Commonly cited kenaf yields can be more than double the yield from wood-based mechanical pulping. In this case, kenaf fossil fuel intensity would be on the order of 2.2 gallons per ton of pulp, approximately 57% greater than fossil fuel intensity for wood pulp.

The margin is greater when considering pulp yields from chemically pulped kenaf bast and core component fibers apportioned for use in the manufacture of uncoated printing and writing papers. In that situation, wood and agrifiber pulp yields are similar. Fuel intensity of kenaf pulp would be more than three times greater than for an equivalent amount of wood-derived pulp. In absolute terms, the difference amounts to about seven gallons per ton of pulp.

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EFFECTS OF NON-WOOD FIBER USE ON ENERGY USE

Manufacturing Energy

Non-wood fiber, by virtue of its chemical structure and lower lignin content, is easier to pulp and bleach. As a result, non-wood fiber typically requires less overall manufacturing energy. Wood fiber, however, has a significant renewable fuel advantage when chemically pulped, as illustrated in Table N1 below, developed by the Paper Task Force.

Table N1. Comparison of Energy Requirements for Softwood vs. Kenaf Pulp Manufacturing (Source: Paper Task Force 1996)

Millions of BTUs per oven-dried ton of pulp

	Softwood (ECF bleaching) [1	Kenaf [2]
DIRECT ENERGY		
Process energy	22.3 - 24.2	15.2
Bleaching chemical energy	10.2 - 10.2	5.7
TOTAL	**32.5 - 34.4**	**20.9**
SELF-GENERATED ENERGY		
Black liquor	23.8 - 19.0	1.4
Wood waste	4.6 - 2.3	
TOTAL	**28.4 - 21.3**	**1.4**
PURCHASED ENERGY	**4.1 - 13.0**	**19.5**

Notes:

[1] The ECF process used here is D(EO)DD. The discussion of bleached kraft pulping processes in White Paper 10A provides additional detail and references.

[2] We have assumed that the kappa number of the unbleached kenaf pulp is 16. Sandwell Inc., *Kenaf Assessment Study,* draft report prepared for the Tallahatchie County Board Charleston, Mississippi, April 19, 1991, p. 18. The typical kappa number for unbleached softwood kraft pulp is 32.

Agrifibers have an energy advantage over wood fiber where mechanical pulping is involved. Process energy requirements related to mechanical pulping of wood fiber have been reported to be approximately 30% greater and are met largely through electricity that is purchased and/or generated through the combustion of fossil fuels.

In the case of chemical pulping, agricultural fiber has a similar total energy advantage, in part due to its reported amenability to the soda-anthraquinone pulping process, which is less intensive than using the kraft pulping process for wood. Amenability to less intensive bleaching is a contributing factor as well. Unlike the case for wood pulping, however, more than 90% of the energy for agricultural fiber chemical pulping is likely to be purchased and/or generated by the combustion of fossil fuels. Purchased energy requirements for bleached kraft mills are cited in Paper Task Force data to range from 13 to 39% of total required energy. Though total energy required for wood pulping and bleaching may be significantly greater than for agrifiber, its reliance on fossil fuel generated energy is dramatically less than that associated with non-wood fiber pulping.

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EFFECTS OF NON-WOOD FIBER USE ON ENERGY USE

Role of Wood-Derived Fuels

Unlike agrifiber, wood is capable of providing not only fiber for the manufacture of wood pulps, but also the bulk of the energy required to sustain the process (Figure N2). During pulping, about 50% of the wood weight in the form of lignin and other wood components dissolves in the spent pulping liquor to yield nearly undegraded cellulose fibers. The ability to effectively recover high levels of energy and chemicals from the black liquor has contributed heavily toward the dominance of the kraft pulping of wood fiber in North America, and it may yet offer other opportunities for new products and biomass-based fuels (van Heiningen 2007).

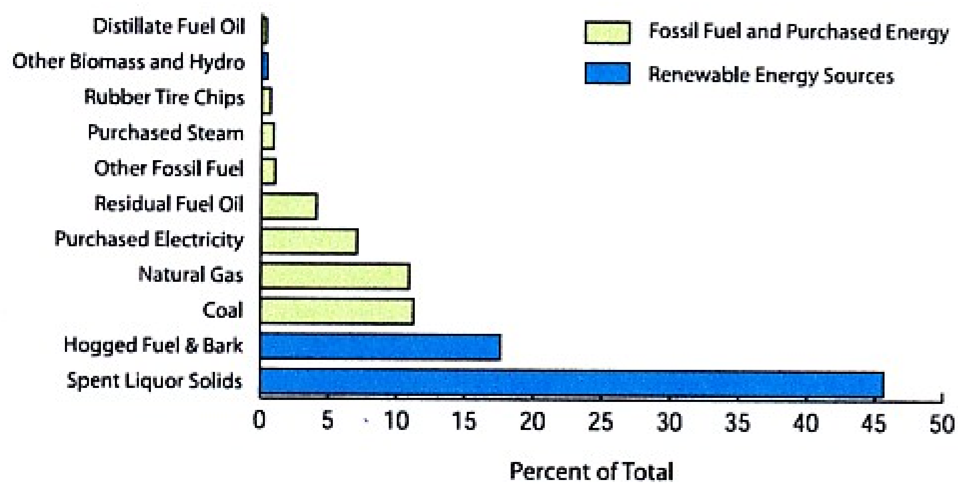

Figure N2. 2006 Pulp and Paper Mill Energy Sources (Source: van Heiningen 2007)

The energy derived from the liquor recovery process produces enough steam (and in some cases electricity) to supply about 50% of the typical North American pulp and paper mill's energy needs. In fact, self-generated and residual fuels accounted for more than half of the pulp and paper industry's total energy requirements in the U.S. (USEPA 2002). Of that, spent pulping liquors provide the single largest self-generated energy source. The industry is also among the nation's leaders in cogeneration performance, with spent pulping liquors supplying the single largest fuel source (35%) to these cogeneration facilities (Clay 1987). In addition, wood waste, hogged fuel and wood bark represent as much as 15% of an individual kraft mill's energy supply needs. This wood residue would otherwise constitute a waste.

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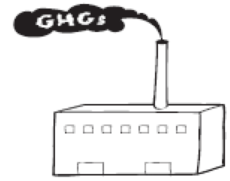


GREENHOUSE GASES

EFFECTS OF NON-WOOD FIBER USE ON GREENHOUSE GAS EMISSIONS

Overview

Notwithstanding a presumed higher yield of dedicated agricultural fiber per unit of land under cultivation, the growth and harvesting of agricultural fiber comes at a cost of greater emission of greenhouse gases (GHGs) than is likely to be associated with wood fiber. The underlying factors include emissions associated with manufacture and use of fertilizers, and the relative intensity of land use for fiber production.

The advantage that the cultivation and harvesting of wood fiber has relative to agrifiber is lost where mechanical pulping is employed. That outcome is attributable to greater yields and the relative ease of pulping that accompany agrifiber. In contrast, wood fiber's cultivation advantage is reinforced with chemical pulping. In that situation, agrifiber's yield advantage is diminished and wood fiber has a dominant advantage in its reliance upon carbon neutral wood-derived fuels.

Click on the links below for more information. Also, see the Greenhouse Gases section of this tool for more information.

More information

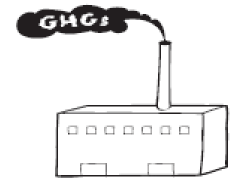
Wood vs. agrifiber products

Role of irrigation and fertilization

Wood fiber procurement

Agrifiber procurement

Agricultural residue vs. dedicated crops



GREENHOUSE GASES

EFFECTS OF NON-WOOD FIBER USE ON GREENHOUSE GAS EMISSIONS

Wood vs. Agrifiber Products

Life cycle assessment (LCA) is a relatively blunt tool for deriving generalizations about the environmental merits of cultivating agricultural fiber compared to those related to wood-derived fiber. Differences in local conditions and site-specific practices can significantly affect the results of such an analysis.

Limited analysis suggests that the overall global warming potential of agrifiber pulps could be about 20% less than that of wood fiber where mechanical pulping is employed. In contrast, agrifiber's global warming potential could be nearly two and one-half times greater where chemical pulping is employed. The advantage that wood fiber pulping has in its access to wood-derived fuels is apparent in Figure N3.

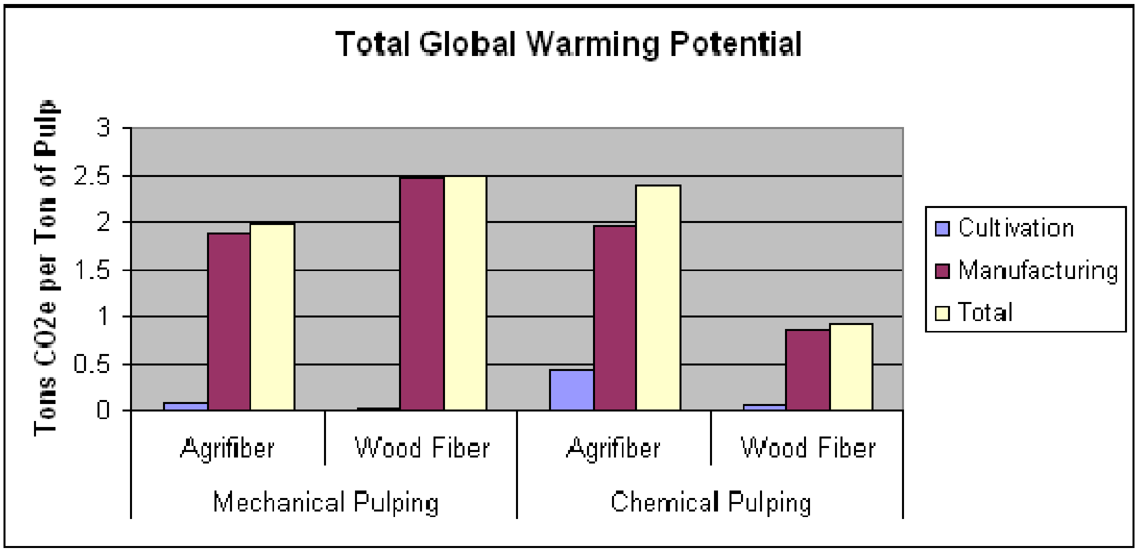


Figure N3. Comparison of Global Warming Potential for Agrifiber vs. Wood Fiber Pulped using Mechanical and Chemical Pulping Processes

For purposes of illustration, it is reasonable to apply an emission potential of 1.5 metric tons CO_2e per 100 cubic meters harvested wood. Based upon experience with food crop production, an emission level of 1.2 metric tons CO_2e per hectare was used for agricultural fiber. Pulp yields were considered comparable in comparing the chemical pulping of wood and blends of kenaf fiber components, at about 1.15 tons per acre. For mechanical pulping, respective yields for wood and agrifiber were taken as 2.5 and 5.5 tons per acre.

The relative magnitude of emissions having significance to global warming potential is dependent upon the pulping process employed. The mechanical pulping of kenaf has a 30% energy advantage over softwood. That difference, by one estimate, is on the order of 600 kwh per air dry ton of pulp (Paper Task Force 2006). If one assumes an emission level of two pounds CO_2 per kwh (representative of coal), the CO_2 emissions associated with mechanical pulping of softwood would exceed those associated with kenaf by 0.6 tons per ton of air dry pulp.

Effects of Non-Wood Fiber Use on Greenhouse Gas Emissions
Wood vs. Agrifiber Products

When pulped chemically, agricultural fiber retains a significant overall energy consumption advantage. However, agrifiber energy requirements must be largely accommodated by purchased fossil fuels sources. Drawing upon Paper Task Force estimates, purchased energy requirements to pulp kenaf exceed requirements for pulping softwood by amounts ranging from 6.5 to 13.4 MBTU per ton of pulp (Paper Task Force 2006). At an approximate emission factor of 0.2 lbs CO_2 per MBTU, the difference amounts to 1.3 to 2.6 tons CO_2 per ton of pulp. Though overall energy requirements may be greater for wood fiber, wood fiber pulping benefits from the prospect that two-thirds or more of its energy requirements are met by wood-derived energy sources.

Reference

Paper Task Force. 1996. *Non-wood plant fibers as alternative fiber sources for papermaking*. White Paper 13. http://c.environmentalpaper.org/documents/1634_WP13.pdf

ENVIRONMENTAL FOOTPRINT COMPARISON TOOL

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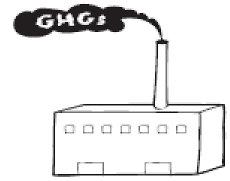

GREENHOUSE GASES

EFFECTS OF NON-WOOD FIBER USE ON GREENHOUSE GAS EMISSIONS

Role of Irrigation and Fertilization

The energy requirements that accompany the irrigation of agricultural land are addressed under the "Energy" section of the Non-Wood Fiber tab of this Tool.

The extent to which the manufacture of fertilizers consumes fossil fuels of significance to greenhouse gas emissions has been discussed previously under Energy. Their agricultural use imposes an additional burden through the release of nitrous oxide (N_2O). There is a lack of data from which to estimate fertilization related N_2O emissions. It is known that the conversion of forests and grasslands to croplands accelerates nitrogen cycling and increases nitrous oxide emissions from the soil. How much, however, remains uncertain. One study indicated that fertilization might increase N_2O emissions the equivalent of 86 to 321 metric tons per million acres per year (USDOE 1999). The impact of this estimated increase would be all the greater when considering that nitrous oxide has a global warming potential that is 300 times greater than CO_2. The N_2O emissions associated with cropland soil amendments are thought to be the largest net source of GHG emissions from cropland agriculture in the U.S. (USDA 2004).

Because wood fiber silvicultural practices rarely employ irrigation and involve significantly less reliance upon fertilization, related greenhouse gas emissions would be proportionately smaller relative to agricultural practices.

References

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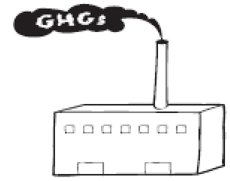

GREENHOUSE GASES

EFFECTS OF NON-WOOD FIBER USE ON GREENHOUSE GAS EMISSIONS

Wood Fiber Procurement

In a recent appraisal of greenhouse gas emissions from forestry operations, Sonne carried out a life cycle assessment that estimated direct and indirect emissions associated with growth of Douglas fir in the Pacific Northwest (Sonne 2006). Though the assessment is related more to the management of trees for saw timber rather than wood pulp, it nonetheless provides a benchmark for silvicultural-related greenhouse gas emission properties.

Of the various unit operations, harvesting emerged as having the greatest greenhouse gas contribution. Where practiced, the piling and burning of slash accumulated from prior harvests constitutes the second largest emission source. Fertilization represents the third greatest. Carbon dioxide accounted for the majority of GHG emissions (67%), followed by nitrous oxide (N_2O) (23%), and methane (CH_4) (10%).

Johnson et al (2005) have also projected emissions of CO_2, N_2O and CH_4 for several silvicultural scenarios in the Southeast and Pacific Northwest. Harvest rotations were 25 and 45 years, respectively. In each region, two levels of management intensity were evaluated, characterized in part by an approximate three-fold increase in nitrogen fertilization. Respective nitrogen applications in the Southeast were 189 and 547 kg per hectare, approximately four times greater than in the Pacific Northwest evaluation.

The various scenarios evaluated in these two studies provide a range of greenhouse gas emission estimates that accompany various treatment regimes and management objectives on different landscapes. Though no single value can be claimed to typify the procurement of pulpwood, the evaluations are useful for establishing an order of magnitude for what might be encountered in silvicultural practice. Values developed in the two referenced studies ranged from as little as 0.8 to as great as 2.75 metric tons CO_2e per 100 cubic meters harvested wood. A value of 1.5 metric tons CO_2e per 100 cubic meters harvested wood might be taken as a representative value.

References

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Sonne, E. 2006. Greenhouse gas emissions from forestry operations: A life cycle assessment. *Journal of Environmental Quality* 35:1439–1450. http://dx.doi.org/10.2134/jeq2005.0159

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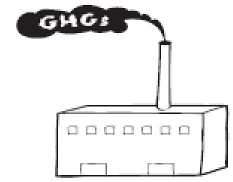

GREENHOUSE GASES

EFFECTS OF NON-WOOD FIBER USE ON GREENHOUSE GAS EMISSIONS

Agrifiber Procurement

In their accounting of the effects of agriculture on greenhouse gas emissions, Robertson and Grace (2004) developed an accounting illustrating the significance of nitrogen fertilizer, agricultural liming and fuel use, as well as N_2O and CH_4 emissions. Robertson and Grace relate the results of actual measurement campaigns in a number of crop systems that show fertilization global warming potential ranging from 50 to 60 g CO_2-equivalents/m^2 per year. The authors go on to show the results of nine years of measurements in a maize-soybean-wheat cropping system in the Midwest United States. Data associated with the practice of conventional tillage show an aggregate greenhouse gas emission rate corresponding to a global warming potential of 1.14 metric tons CO_2e per hectare. Of this, 46% is attributable to N_2O emissions and 24% to fertilizer-related CO_2 emissions. This illustrates the dominance of fertilization in the emission equation.

The use of no-till cultivation has been demonstrated to show a significant, though perhaps transitory, reduction in the net emission level as additional soil carbon is sequestered to a new equilibrium level. Mosier et al (2006) have spoken to this, as well as an issue related to soil organic carbon dynamics. Their experiments evaluated global warning potential for a number of management regimes involving irrigated corn cultivation over a three-year period. Among the scenarios was conventional tillage with a fertilizer application rate of 134 kg nitrogen per hectare. For that scenario, the annual assessments of global warming potential ranged from 800 to 1800 kg CO_2e per hectare per year, and averaged 1.3 metric tons CO_2e per hectare. This estimate was derived through the typical way in which CO_2 exchange is estimated, i.e., measurement of the change in soil organic carbon.

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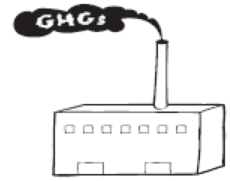
Robertson, G.P. and P. Grace. 2004 Greenhouse gas fluxes in tropical and temperate agriculture: The need for a full-cost accounting of global warming potentials. *Environment, Development and Sustainability* 6: 51–63. http://dx.doi.org/10.1023/B:ENVI.0000003629.32997.9e



GREENHOUSE GASES

EFFECTS OF NON-WOOD FIBER USE ON GREENHOUSE GAS EMISSIONS

Agricultural Residue vs. Dedicated Crops

Any global warming potential associated with crop residues would be predominantly allocated to the crop from which it originated. Carbon dioxide emissions associated with residue burning practices constitute a neutral greenhouse gas source, though other gaseous combustion products such as N_2O and CH_4 would have some contribution. The gain associated with using residues, as opposed to burning them, would have to be balanced against the direct and indirect emissions associated with additional soil fertilization requirements necessitated by residue recovery. Similar to the case for dedicated fiber crops, manufacturing emissions associated with chemical pulping of agricultural residues would be more significant, on a relative basis, than those related to using wood fiber, due to the advantages associated with wood-derived fuel.

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CHLORINATED COMPOUNDS

EFFECTS OF NON-WOOD FIBER USE ON CHLORINATED COMPOUNDS

Overview

Because of structural differences and lower lignin content, agricultural fibers are more easily bleached and pulped than wood fiber. Thus, agrifiber is thought to be more amenable to bleaching with processes that utilize no chlorine-bearing compounds, or totally chlorine free (TCF) bleaching.

Additional information on Chlorinated Compounds that may be associated with bleaching can be found in the Chlorinated Compounds section of this tool.

More information

Bleaching of non-wood fiber

ENVIRONMENTAL FOOTPRINT COMPARISON TOOL

A tool for understanding environmental decisions related to the pulp and paper industry

CHLORINATED COMPOUNDS

EFFECTS OF NON-WOOD FIBER USE ON CHLORINATED COMPOUNDS

Bleaching of Non-Wood Fiber

The Paper Task Force Report cites experience where non-wood fiber has been bleached to high brightness (90+ ISO) with totally chlorine free (TCF) bleaching sequences following alcohol-based pulping. In another example, pulped agricultural residue bleached in a TCF processes was blended in near equal quantities with elemental chlorine free (ECF) bleached old corrugated containers for the production of 80 brightness uncoated printing and writing paper (Paper Task Force 1996).

In the United States, paper produced commercially with 100% TCF kenaf pulp has had a typical brightness of 72 ISO and would not accommodate expectations for bright white paper (Rymsza 1997). However, there may be an option to incorporate non-wood fiber pulp with other wood fiber sources, including pre- and post-consumer wastepaper, brightened by process chlorine free (PCF) and elemental chlorine free (ECF) bleaching, to achieve a higher final brightness product.

References

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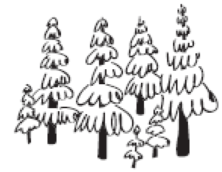

WOOD USE

EFFECTS OF NON-WOOD FIBER USE ON LAND AND WOOD USE

Overview

Agricultural practices impose a burden on the land and are accompanied by impacts on habitat quality. Though it is possible for dedicated agricultural crops to offer greater fiber yields and require less land than wood fiber, there are additional effects that need to be considered as potential trade-offs. Denison, a principal in the Paper Task Force appraisal of environmentally preferable paper, notes:

> *"Many are concerned with the implications of intensive forestry on habitat value and biodiversity. Indeed, many methods for intensive silviculture compromise forests' ecological values. It must be realized, though, that annual crops require the same considerations. It is hard to imagine that the biological value of even the most intensive of tree plantations would ever be lower than that of an agricultural field of comparable size. Indeed, I would argue that, acre for acre, from an ecological perspective, habitat value, biodiversity and water quality protection and soil carbon storage would all be higher for silviculture relative to agriculture because harvesting, replanting, fertilization and pesticide application only occur on a multi-year basis rather than annually."* (Conservatree n.d.)

The diversity of plant and animal life found within a managed forest does depend on the application of sound management practices tailored to achieving biodiversity and forest productivity. Fiber sourced from forestlands managed within the framework of sustainable forest management certification programs (such as those under the Sustainable Forestry Initiative, Canadian Standards Association, or Forest Stewardship Council) has been managed through the application of practices oriented toward protection of biodiversity.

Reference

Conservatree. n.d. Environmental Paper Listening Study Question 42: What is the comparison of impacts between agricultural residues and on-purpose crops? http://www.conservatree.org/paperlisteningstudy/TreeFree/question42.html

More information

Land area requirements

Land disturbance

Habitat effects

EFFECTS OF NON-WOOD FIBER USE ON LAND AND WOOD USE

Land Area Requirements

Land area required for the sourcing of fiber depends upon the specific fiber, the intensity with which it is cultivated, and the fiber mix and processes used to produce an end product. Dedicated agricultural crops such as kenaf are capable of yielding more fiber per acre of land cultivated, though not necessarily more pulp combinations suitable for specific paper grades. Mechanical pulping of softwoods, for example, would require a larger land area for fiber growth than the production of chemi-mechanical pulps from whole-stalk kenaf. Yet the land advantage of dedicated agricultural fiber would be lost in the blends of short and long fiber required for printing and writing papers.

Fiber yield, whether agricultural or silvicultural, is not fixed. There has already been significantly increased agricultural productivity, and silvicultural productivity is at the threshold of similar improvement. Therefore, relative land area requirements are likely to change over time. More important than the amounts of land that must be dedicated to provide wood or agricultural fiber is the impact those respective land uses have on the land itself and its habitat values.

Recommended Reading

Conservatree. n.d. Environmental Paper Listening Study Question 42: What is the comparison of impacts between agricultural residues and on-purpose crops? http://www.conservatree.org/paperlisteningstudy/TreeFree/question42.html

Blann, K. 2006. *Habitat in agricultural landscapes: How much is enough? A state-of-the-science literature review*. Washington, DC: Defenders of Wildlife. http://www.defenders.org/resources/publications/programs_and_policy/biodiversity_partners/habitat_in_agricultural_landscapes.pdf

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WOOD USE

EFFECTS OF NON-WOOD FIBER USE ON LAND AND WOOD USE

Land Disturbance

A fundamental distinction between agriculture and silviculture is the frequency, extent, and intensity of land disturbance. Unlike the annual rotation of agricultural cropland, silvicultural management involves rotations of 10 to 20 years or longer. Silvicultural management would involve site intervention a handful of times over that lengthy period, for site preparation, planting, suppression of unwanted vegetation, and harvesting. An agricultural crop could require as many as twice that number of interventions—every year. Annual crop rotation and the associated frequency of soil disturbance exact a toll on the structure of agricultural soils. Among the results are diminished soil porosity and slower water infiltration rates. Silvicultural practices, even when intensive, impose a lighter touch. The larger numbers of root channels extending into subsoil, and a higher content of large soil pores contribute to greater rates of water infiltration and percolation than is the case for agricultural soils. Therefore, there is diminished runoff and soil erosion potential associated with forestlands than with agricultural lands.

Because of the more intensive nature of agricultural practice, soil nutrients removed with the harvest must be replenished to sustain productivity. Kenaf, the most commonly cited non-wood option for papermaking, requires fertilization to achieve desirable yields. Crop residues, which have the inherent advantage of having been derived from an existing crop, are typically left on the land surface, burned, or incorporated back into the soil to restore soil organic matter. Appropriating the residue as a source of agricultural fiber must be balanced against environmental impacts (soil erosion), maintaining soil carbon levels (sequestration of greenhouse gases), and preserving or enhancing productivity (soil tilth and nutrient cycling). Additional fertilization is required depending on the extent of residue recovery, to sustain soil productivity.

Unlike the annual treatments required for agricultural crops, forestlands normally receive zero to three chemical applications during a rotation of 10 to 25 years, depending on tree species and region. In some regions, forestlands receive no chemical treatment. In cases where chemicals are applied to forestlands, they are used to enhance tree growth, reduce unwanted competitive vegetation, and control diseases and insects. Overall, the amount of chemical use in forestry settings is an order of magnitude less than in agricultural uses.

Recommended Reading

Conservatree. n.d. Environmental Paper Listening Study Question 42: What is the comparison of impacts between agricultural residues and on-purpose crops? http://www.conservatree.org/paperlisteningstudy/TreeFree/question42.html

Blann, K. 2006. *Habitat in agricultural landscapes: How much is enough? A state-of-the-science literature review*. Washington, DC: Defenders of Wildlife. http://www.defenders.org/resources/publications/programs_and_policy/biodiversity_partners/habitat_in_agricultural_landscapes.pdf

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EFFECTS OF NON-WOOD FIBER USE ON LAND >KA TLLA USE

Habitat Effects

Row crop agriculture spanning large fields of commodity crops provides hospitable habitat for a significant number and diversity of species, particularly those that are open-habitat and grassland species. However, forested areas beyond the minimum seral stages provide significantly more environmental volume than does low-stature vegetation. When that volume contains trees and shrubs of diverse heights and stratifications, more niches are available for species use (MacArthur and MacArthur 1961; Moss 1978; Southwood et al. 1979; August 1983). This relationship can be demonstrated in the percentage of native biodiversity that is forest-dwelling in North America (Bunnell 1992). The expansion of more intensively managed cropland relative to hay and pasture, when accompanied by a reduction in field borders and unique habitat areas, may exacerbate this difference.

The harvesting of a timber stand does result in localized habitat alteration. This alteration is transitory and takes place concurrently with regrowth in other areas within the overall forested landscape. Managed forestlands are comprised of multiple age classes such that the landscape overall contains different habitat types. It may be viewed as a patchwork of uncut stands, clearcuts, and partial cuts. Different habitat structure is produced within individual stands based on differing silvicultural treatments. All of these standard silvicultural techniques, conducted in different aged plantations across landscapes, provide habitat diversity, which generally equates to overall biodiversity (NCASI 2006).

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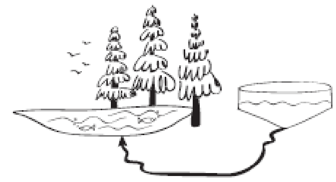

EFFECTS OF NON-WOOD FIBER USE ON DISCHARGE TO WATER

Overview

Non-wood fiber wastewater streams are equally responsive to wastewater treatment technologies commonly employed for managing conventional pollutants at wood fiber-based pulp and paper facilities. That said, the lower lignin content and differences in cell structure of non-wood fiber generally contribute to less intense mechanical or chemical processes required to pulp and bleach non-wood fibers. This leads to lower discharges of substances contributing to chemical oxygen demand (COD) in wastewater.

Follow the links below for more information.

More Information

Non-point source pollution

Manufacturing wastewaters

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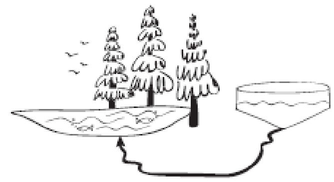

EFFECTS OF NON-WOOD FIBER USE ON DISCHARGE TO WATER

Non-Point Source Pollution

Silvicultural-related use of fertilizers and pesticides or herbicides in managed forests is less intense than chemical use in agriculture. Forest fertilization, where used, usually has small short-lived impact on nutrient losses. This is attributed to the relative infrequency of fertilization and lower fertility of most forest soils. The rigorous application of forestry regulations, best management practices, and streamside management zones has a further attenuating effect (Soil Science Society of America 2008; NCASI 2009).

To the extent that less productive lands are brought into cultivation for purposes of fiber crops, surface and groundwater impacts may be even greater. On average, land shifting in and out of cultivation is more vulnerable to erosion (e.g., from rainfall or wind) and has greater nutrient runoff and leaching potential than more productive cropland. Expectations that increase incentives for crop cultivation and stimulate production on economically marginal land may have disproportionately large unintended environmental consequences (Lubowski et al. 2006).

The greater frequency and intensity of cropland cultivation relative to forest management contributes to greater soil loss. As a relative comparison, soil loss from established forests is commonly 0.02 tonne/ha/yr compared with 0.05-0.37 tonne/ha/yr from pastures and 1.5 to more than 8 tonne/ha/yr for annual crops (Turner et al. 2004).

It is generally accepted that silvicultural best management practices and streamside management zones are effective for protection of water quality (NCASI 2009). The development and implementation of forestry BMPs has greatly reduced nonpoint pollution from silvicultural activities. Certification programs such as those managed by the Sustainable Forestry Initiative, Forest Stewardship Council, and Canadian Standards Association provide additional assurance that wood fiber suppliers are conscious of water quality protection practices and are applying them as site circumstances dictate.

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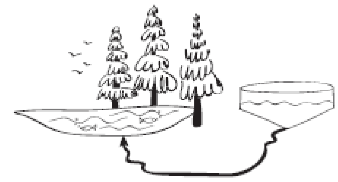

DISCHARGES TO WATER

EFFECTS OF NON-WOOD FIBER USE ON DISCHARGE TO WATER

Manufacturing Wastewaters

A major impetus for the pulping of wood was the development of a pulping liquor recovery process capable of capturing both the cooking chemicals for reuse and the energy derived from the dissolved wood constituents to reduce the need for additional power generation.

In contrast, the pulping of cereal straws results in pulping liquors that are relatively deficient in energy value, and their silica content brings the potential for fouling the surfaces of conventional liquor recovery process equipment. Alternative approaches for pulping of straw are evolving, but whether they will achieve the related economic hurdles remains to be seen. Absent such developments, management of straw pulping liquors remains a challenge.

Apart from this challenge related to cereal straw pulping, agrifiber wastewater streams are equally responsive to wastewater treatment technologies commonly employed for managing conventional pollutants. Data assembled by the Paper Task Force (see Figure N1) provide representative ranges of wastewater quality.

	Kenaf		Softwood
Bleached chemical pulps	Kraft [1]	Soda [2]	Kraft [3]
Effluent flow (gallons per air-dried ton of	36,000	20,000	18,700
Effluent Quality (kg/air-dried metric ton of			
Biochemical oxygen demand	1.5 - 2.3	5.8	0.3 - 6.7
Chemical oxygen demand (COD)	18.0 - 22.5		14.4 - 72.8
Total suspended solids (TSS)	3.0 - 4.5		0.2 - 9.8

Notes:
All three mills have secondary treatment.
[1] The Phoenix mill produces market pulp from wholestalk kenaf. Reported treatment efficiencies are 97% for BOD and TSS and 87% for COD. V. P. Leekha and S.K. Thapar, "Experiences in Kenaf Pulping in Thailand," *TAPPI Proceedings of the 1983 Pulping Conference* (Atlanta: TAPPI Press, 1983) pp. 288-293.
[2] Sandwell Inc, *Kenaf Assessment Study*, draft report prepared for the Tallahatchie Board of Supervisors, Charleston, Mississippi, April 19, 1991, p. 16.
[3] Effluent quantity: See White Paper 10A.
Effluent quality: U.S. EPA, *Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Point Source Category*. Washington: U.S. EPA Office of Water, EPA-821-R-93-019, pp. 6-48 - 49, 10-42.

Figure N1. Relative Effluent Flows and Effluent Quality for Kenaf vs. Softwood Fiber (Source: Paper Task Force 1996)

Lower lignin content and differences in cell structure generally contribute to less intense mechanical or chemical processes required to pulp and bleach non-wood fibers. These structural differences also contribute to lower discharges of substances contributing to chemical oxygen demand (COD). Effluent standards in the U.S. for bleached kraft mills where pulp and fine papers are produced reflect annual average allowable discharges of 3.09 and 6.59 kg per air dried metric ton for biochemical oxygen demand (BOD) and total suspended solids (TSS), respectively (*Federal Register* 1998). COD is not typically regulated in North America.

Treated effluent quality cited in Figure N1 suggests that effluent quality comparable to that associated with bleached kraft pulping of softwood would require less intense wastewater treatment. Note that despite potential advantages such as this, the "Phoenix mill" mentioned in Figure N1 reverted to pulping bamboo and planted eucalyptus (Stalk, Frese, and Alexandersen 2003), with kenaf amounting to only 5% of the mill fiber supply, due to inadequate kenaf supply for economic reasons.

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