Tree-Free Paper:
A Path to Saving Trees and Forests?

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Introduction

Since about 1870 most paper worldwide has been made using wood. Over the preceding 1,765 years (before 1870) non-wood fiber was the basis for papermaking. Prior to that, people utilized papyrus or parchment as a writing substrate – the former made of crisscrossing coarse fibers of the papyrus plant, the latter made from skins of animals. The first paper was largely made from hemp, but use of rattan, mulberry, bamboo, rice straw, and even seaweed occurred over the succeeding 600-800 years.[1] Later, there was a shift to linen rags as a raw material as knowledge of papermaking found its way into North Africa sometime after the year 800. Rags remained the preferred source of fiber for making paper for about a thousand years until development of processes for grinding and then chemically pulping wood were developed in Europe and the United States in the mid-1850s.[2]

Regions lacking abundant forest resources continued to rely on sources of fiber other than wood to make paper. Bagasse, flax, various grasses, cereal straw, cotton linters, hair, leaves, and more recently, hemp, oil palm, giant reed (*Arundo donax* L.), banana, polyester, calcium carbonate and polyethylene have all been used in making paper. As of 2011, the percentage of global pulp production from non-wood fiber was about 4.2%[3]; this compares to 6.7% non-wood fiber in 1970.

Recently, in some circles, there has been growing interest in moving away from reliance on trees and wood as a papermaking material, and toward agricultural-based or other raw materials.[4] A primary driving force behind what is widely referred to as "tree-free paper" campaigns appears to be a desire to save forests and trees.[5]

Thus far, serious consideration of the potential environmental impacts of fiber alternatives is largely lacking in the quest for alternatives to wood-based paper. Since production, procurement, transport, and processing of *all* raw materials results in environmental impacts, it is important to identify and, to the extent possible, quantify likely impacts before making conclusions about environmentally preferable raw material sources and production technologies.

In this report we build upon an earlier Dovetail examination of tree-free paper.[6] Herein we present findings of various investigations into environmental impacts of alternative fiber and paper production systems, including a recent cradle-to-grave life cycle assessment (LCA) of alternative fiber use in production of tissue. We also look into the underlying assumption in the tree-free paper movement – that reducing or avoiding altogether the use of wood-derived fiber in making paper would, in fact, lead to more extensive forests and more trees.

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[1] IPST (2006) (http://www.ipst.gatech.edu/amp/collection/museum_invention_paper.htm)
[2] Libby (1962)
[3] Suhonen (2013)
[4] Gleason (2013) (http://www.conservatree.org/treefree.html)
[5] Breyer (2013) (http://www.mnn.com/money/sustainable-business-practices/stories/woody-harrelson-fights-for-the-forests-with-his-tree)
[6] Bowyer et al. (2004) (http://www.dovetailinc.org/report_pdfs/2004/dovetailtreefreepap9204.pdf

Paper Production and U.S. Forests

Approximately 79 million tons of paper was produced in the U.S. in 2013. Recovered fiber accounted for 37% of the wood fiber used. Some recovered fiber is lost in processing, with the result that about a third of the volume of paper and paperboard produced is made up of recovered fiber. The remaining two-thirds come from trees harvested as pulpwood, wood chips, and other residues obtained from sawmill trimmings. On a mass basis, over 65 million tons of roundwood (dry basis), or 36% of the annual U.S. timber harvest, is used each year in manufacturing paper and paperboard. When chips and other residues are considered, the percent of harvest going to paper and paperboard production rises to about 47%.

Typically, more than 65% of the nation's pulpwood harvest is derived from the Southeastern region. In recent years, this percentage has risen to over 81%. Virtually all of that harvest is obtained from privately owned forestland. Individuals and families, private investment groups, and the forest industry own 57% of forestland in the United States. These lands provide 89% of the annual wood harvest (Oswalt et al. 2014).

Annual removals of wood in the U.S. are less than half the annual increment. In other words, each year forests in the U.S. grow more than twice as much wood as is harvested. The annual harvest amounts to about 1.3% of total growing stock volume. Despite, and largely because of, ongoing removals that are only a portion of annual growth, forests in the United States are increasing in extent. Also, the volume of trees contained within U.S forests is rising steadily. Today the U.S. has more forested land than in the early 1900s. Moreover, net growth has exceeded removals for at least 6 (and likely 7-8) consecutive decades.[7] The result is the volume of wood stored in the nation's forests has increased substantially over that period even in the face of substantial, ongoing harvest activity.

Fiber Sources for Papermaking - Pulpwood, Fiber Crops, Crop Residues and Plastic Paper

To understand and compare the environmental impacts associated with production of paper and various types of alternative fiber, it is necessary to begin with an examination of various production systems.

Pulpwood Production

Gathering and processing of all raw materials, including collection of materials for recycling, results in environmental impacts. In the case of obtaining wood for papermaking, pulpwood is typically obtained through 1) thinning of forest stands being grown to provide raw material for production of multiple products including lumber, plywood, and other long-lived products, 2) patch clearcutting of smaller diameter, faster growing tree species managed specifically for pulp production, and/or 3) collecting sawmill residues (chips). Wood fiber is also collected via recycling. As mentioned previously, the southeastern U.S. is a major source of pulpwood harvesting. Pulpwood harvests in the Southeast involve both thinning and patch clearcutting.

[7] Periodic forest inventories by the U.S. Forest Service inventories have documented annual growth in excess of removals since 1952, and further research suggests that this trend likely began one to three decades earlier (Frederick and Sedjo 1991; Birdsey et al. 2006).

Thinning in southern pine stands being managed for multiple products including sawtimber typically occurs at 8-10 year intervals until 20-30 years of age. Each removal, beginning with the second thinning treatment, results in an increasing proportion of wood used in producing lumber and other long-lived products. The sawtimber harvest occurs at 30-40 years of age or about a decade following the final thinning, followed by direct seeding or replanting. When a forest stand is replanted following harvest, it is common to plant at a relatively high density so that the canopies of the growing trees close quickly in order to shade out other plants, shrubs or grasses that compete with the trees for water and nutrients. Farmers and gardeners basically practice the same technique when optimizing plant and crop spacing in order to maximize site productivity and to give desired plants the best advantage. Since trees are planted so densely, it is necessary to thin them periodically to manage competition for water, sunlight, and nutrients and maintain forest health.

In preparation for replanting of pine, steps may be taken to control competition through the use of burning or herbicide application. A second application of herbicide may occur at age 3-4. Fertilizer may also be applied 1-2 times, with the first application at or near the time of planting, and a second application at age 4-7 if necessary. Thereafter, stand entries occur in conjunction with thinning cycles. Overall, during a 35-40 year growth/harvest cycle of southern pine, site intervention occurs six to ten times (1-2 times in preparing the site, once to plant or seed, 1-2 times to suppress competition, 0-2 times to fertilize, 2-3 times to thin, and once to clear the site in preparation for replanting). Pine managed only for pulpwood is grown on a harvest cycle of about 20 years. In this case, the number of stand entries during the growth/harvest cycle is three to eight. Typical southern pine yields through a full rotation are 2.0 to 3.0 dry tons of wood per acre per year (4.5 to 6.7 dry metric tons per hectare per year).

14-Years after Clearcutting of Southern Yellow Pine, Followed by Replanting

Forest management varies by region and forest type. It is influenced by the local ecology, climate, growth rates and tree species being grown. Outside of the Southeast, which enjoys a more generous growing season and higher tree growth rates than other regions, pulpwood is commonly obtained from less intensively managed forests (i.e., with fewer stand entries). An example is harvesting of aspen in Minnesota and Wisconsin.

In the Lake States region, fast-growing and short-lived aspen (typical life expectancy is 70-80 years) is harvested in 40-50 year intervals to obtain wood for papermaking and production of structural panels. Aspen is a pioneer species and requires direct sunlight early in the growth cycle. Harvest is therefore commonly done by patch clearcut with the desired size of the clearing being at least twice the height of the surrounding forest to ensure that the opening receives full

sunlight. Because aspen re-sprouts from its root system (root suckering) following harvest, no replanting or seeding is necessary. Use of herbicides or fertilizer is also generally unnecessary because new trees regenerate fast enough and in sufficient density to outpace competing shrubs, plants and grass. Thinning at age 15-20 occasionally occurs, although this is not common because it is not very economical (e.g., it would usually be a "pre-commercial thinning" because the trees are too small to market at that age and the landowner would not receive any income from the thinning). In the case of typical aspen pulpwood management, the number of stand entries in the 40-50 year growth harvest cycle is 1-2.

Strip Clearcutting in Aspen

Aspen Site One-Year After Clearcut Harvest

Typical aspen yields are 20-25 cords per acre at a harvest age of 40-50 years, equating to a growth rate of about ½ cord per acre per year, with the best sites yielding more than double that. This translates to a dry wood yield of 0.4 to 0.9 dry tons per acre per year (0.9 to 2.0 metric tons per hectare per year). Yields can be increased if thinnings are done at mid-rotation.

Fiber Crops

In the mid-1950s the U.S. Department of Agriculture set about to identify crops that could help to expand and diversify markets for American farmers. Because there was little in the way of historical knowledge to build on regarding industrial raw material crops, a massive crops screening program was launched. The initial emphasis was on studying fiber crops that could be used as raw materials for pulp and paper manufacture. More than 1,200 samples of fibrous plants from about 400 species were screened, taking into consideration many diverse technical and economic factors (Atchison 1996).

Based on the initial evaluation, the 61 most promising fibers were subjected to extensive pulping tests. By 1961, researchers had narrowed the list to six leading fibrous materials: kenaf, crotalaria, okra, sesbania, sorghum, and bamboo. After two more years of intensive work, kenaf (*Hibiscus cannabinus* L.) emerged as the top candidate for further research (Kugler 1990). Over the next 15 years kenaf was the focus of intensive investigation. Information was collected regarding technical and economic aspects of plant growth and harvest, storage, and conversion to pulp and paper products. Potential markets were also investigated.

In the early 1990s interest in alternative crops re-emerged in the form of a new alternative crops initiative of USDA (Abrahamson and Wright 2000) and a new focus on potential energy and chemical crops. These efforts continue today. At this writing it is unclear how this research might impact the U.S. pulp and paper industry. At least one major company – Kimberly Clark – is currently investigating cellulosic fiber options. This includes possibilities for purpose-grown

fiber and agricultural crop residues for use in manufacturing tissue products. Fiber sources being investigated include kenaf, bamboo, giant reed (*Arundo donax*[8]), and wheat straw.

For purposes of this report we focus on the three most commonly promoted fiber crop alternatives – bamboo, kenaf, and hemp.

Bamboo, the environmental attributes of which were discussed in a recent Dovetail report[9], was recently identified by Kimberly Clark Corp. as a prime candidate for addition to fiber supply options for use in tissue manufacture. The long, unbranched stalks of bamboo are marked by nodes that appear periodically along their length; in between those nodes the stalk is hollow, with outer walls averaging 10-15 mm (0.4-0.6 in.) in thickness. Bamboo ranks high as a candidate for supplying fiber for the manufacture of pulp and paper because fiber lengths fall in the same range as wood (some are about the same as southern yellow pine). Bamboo stalks can be easily chipped, and pulping and bleaching conditions as well as pulp yields are very typical of those of wood.

Kenaf produces unbranched stalks with a relatively thin outer layer that accounts for 35-40% of stalk weight. Fibers of this layer are about the same length of those of southern pine. The holocellulose (cellulose + hemicellulose) fraction of the outer layer of the stalk is the same to as much as 8% higher as in wood. Also, the proportion of lignin is dramatically lower than in wood (40% lower). These are both highly desirable features. The center of the stalk, however, consists of fibers that are shorter than hardwood fibers and generally shorter even than the juvenile fibers of wood. Chemically, the holocellulosic content of kenaf's core fiber is comparable to that of wood and the lignin content is lower. Despite short core fiber length, research by USDA and others generally indicates excellent properties of kenaf pulp and paper.

Kenaf
Photo: Western Illinois University

Hemp stalks are similar to those of kenaf, consisting of a long-fibered outer layer that comprises 30-35% of stalk volume, and an inner core consisting of short fibers. The fibers of the outer layer of the hemp stalk are longer than those of wood, and chemically they contain considerably more cellulose and holocellulose, and significantly less lignin than either hardwoods or softwoods. These characteristics provide for a high pulping yield. Long hemp fibers from the outer part of the stalk have found specialty applications in production of thin, high-strength papers such as used for cigarette paper, bank notes and bibles. In contrast, the core of hemp stalks, which make up the remaining 65 to 70% of stem weight, consist of fibers that are significantly shorter than even the juvenile fibers of most hardwood and softwood species. In addition, the cellulose content of hemp core fiber is lower than that of wood. Because of the high proportion of short, low yield fiber and substantial differences in the outer layer and core of hemp stalks, different manufacturing processes are needed to achieve optimum processing of the two fractions. There are, moreover, differences in markets for the

[8] Although Arundo donax is the scientific name and giant reed the common name for this plant, it is becoming common practice to refer to this species using the scientific name, and that is what we have done in the remainder of this report.
[9] Bowyer et al. (2014) (http://www.dovetailinc.org/report_pdfs/2014/dovetailbamboo0314.pdf)

two types of fiber. Consequently, separation of the outer and core segments are recommended prior to pulping, a potentially costly requirement.

Crop Yields

As intensively managed crops, annual yields obtainable from agricultural fiber crops are generally higher than from forest plantations or naturally managed forests. The differences are most significant when annual agricultural fiber crops are compared to natural northern forests where growing rates and seasons are more limited (Table 1).

Table 1
Reported Yields for Various Current and Potential Sources of Papermaking Fiber

Fiber Crops						
	Annual Yield of Biomass, Dry Basis					
	Combined		Stalk [h/]		Leaf [h/]	
Species/Location	t/ha	short tons/acre	t/ha	short tons/acre	t/ha	short tons/acre
Kenaf/ U.S. [a/]	17.5	7.8	14.2	6.3	3.3	1.5
Moso bamboo/China [b/]	7.0-10.0 (up to 35.0 in optimal conditions)	3.1-4.5 (up to 15.6)	6.1-8.7 (up to 30 in optimal cond.)	2.7-3.9	0.9-1.3	0.4-0.6
Hemp/ U.S. [c/]	5.4	2.4	4.9	2.2	0.5	0.2

Forests/ Tree Plantations								
	Annual Yield of Wood, Dry Basis							
	Combined		Wood		Bark		Tops/Leaves	
Species/Location	t/ha	short tons/acre	t/ha	short tons/acre	t/ha	sht t/ac	t/ha	sht t/ac
Loblolly pine, LA [d/]	5.4-7.2	2.4-3.2	3.8-5.1	1.7-2.3	0.8-1.1	0.04-0.05	0.8-1.1	0.04-0.05
Slash pine, GA [e/]	8.6	3.8	6.0	2.7	1.3	0.6	1.3	0.6
Aspen, WI [f/]	1.3-3.1	0.6-1.4	0.9-2.0	0.4-0.9	0.1-0.3	0.1	0.3-0.8	0.1-0.4
White Spruce, MN [g/]	4.2	1.9	2.9	1.3	0.6	0.3	0.6	0.3

[a/] Data is average of measured yields in 17 locations within 13 states as reported by various investigators (Bowyer 1999).
[b/] Data from Yiping and Henley (2010).
[c/] Data from numerous studies/field trials as reported by Bowyer (2001), Table 6.
[d/] Clason 1992; 35-year rotation.
[e/] Jones 1986; 20-year rotation.
[f/] Figures based on common yields at harvest in Wisconsin, and biomass yields as reported by Perala and Laidly (1989).
[g/] Rauscher 1985; 40-year rotation.
[h/] Leaves assumed to account for 13% of total yield.

Recorded yields for annually harvested kenaf, for instance, are about 2.4 times those of plantation-grown southern yellow pine harvested on a 20-year cycle and 7-15 times greater than wood obtained from managed natural northern forests harvested on a 50-year cycle (Table 1). While reports of very high annual yields for bamboo and hemp can be found in the literature,

average yields obtained by those who have actually produced fiber in a production environment are significantly lower and similar to annual fiber production in southern pine plantations.

Production System Impacts

The increase in fiber yields from purpose-grown fiber crops could reduce the area of land needed for production of papermaking fiber, as well as reduce periodic harvesting within forests (more on this later). However, greater productivity involves a tradeoff between relatively low intensity management (and periodic harvesting of trees) over large land areas, and intensive (e.g., annual) fiber cropping over smaller land areas. Differences between extensive low and more concentrated high intensity management may be difficult for the casual observer of forestry and production agriculture operations to appreciate. Perspective is provided by Scott and Taylor (1990) who outlined the steps involved in production of an annual crop of kenaf, including: preparation of the land for planting (chisel, disc, disc/herbicides/disc, done twice), application of pre-plant fertilizer, bedding, seeding and planting, application of side-dressing, cultivation, and harvesting. This sequence of production steps results in direct-site impacts, including soil disturbing activities[10], occurring about 700 times over a 50-year period, and includes annual applications of fertilizer and herbicides. This is similar to the cropping sequence involved with production of hemp. Production of bamboo involves slightly fewer inputs, but nonetheless would likely involve 200-300 passes across the landscape over a 50-year period. In contrast, production of wood in natural forests or forest plantations typically involves fewer than 10 site entries or soil disturbing activities over a 50-year period. For further information and in-depth analyses of production and technical aspects of bamboo, kenaf, and hemp cropping for paper fiber production see Bowyer et al. (2014), Bowyer (1999, 2001).

Crop Residues

The use of crop residues as papermaking raw materials has been practiced for a very long time. Wheat straw chemical pulp was first produced in 1827 (Moore 1996). Crop residues, such as bagasse (or sugarcane residue), have been used for many years in making paper in China, India, Pakistan, Mexico, Brazil and a number of other countries (Pande 1998).

Suitability of Crop Residue Fiber for Papermaking

U.S. research examining potential uses of crop residues as a papermaking raw material dates back to at least World War II (Atchison 1996). In the 1940s, 25 mills in the Midwest produced almost one million tons of corrugating medium[11] annually from straw. By 1945 the Technical Association of the Pulp and Paper Industry (TAPPI) established an agricultural residues committee. Momentum in the non-wood fiber industry was lost following the war because of the high costs of gathering and processing straw, and the return to pulping of hardwoods on the part of the paper industry. The last straw mill in the U.S. closed in 1960.

In the 1990s new research initiatives focused on agricultural residue-based paper technology and industry development were launched (Alcaide 1993; Jewell 1999). In 1996, the Paper Task Force, a group of paper industry experts, convened under the auspices of the Environmental

[10] Soil disturbing activities such as plowing, disking, planting, cultivation, harvesting, etc. increase soil erosion risks and impact soil carbon storage.

[11] Paperboard passed through a corrugating machine to give it wavy ridges called flutes, used in making container boxes (http://www.businessdictionary.com/definition/corrugating-medium.html)

Defense Fund and Duke University. The Task Force was funded by several large U.S. corporations and issued a report that included examination of the potential for commercial paper production from non-wood fiber. Cereal straws were among the fiber sources examined. It was concluded that 1) straw can be satisfactorily pulped, 2) technology improvements are likely to improve pulp properties and reduce pulping costs, 3) transport and storage of straw are factors likely to limit plant capacity (and thus perhaps to inhibit achievement of optimum economies of scale), and 4) the most likely use of straw pulp was as an additive to wood pulp. Overall, the outlook regarding use of straw pulp was positive.

Recently, the previously mentioned Kimberly Clark study (Thomas and Liu 2013) also found promise in wheat straw as a fiber source. One caveat is that fiber from agricultural residues were found to behave similarly to recycled fibers, and perhaps best suited to short-fiber applications, a finding that parallels the Paper Task Force conclusion regarding use of cereal straw fiber as a pulp additive.

Availability of Crop Residues

Although a wide variety of crops in the U.S. might provide fiber for the paper industry, commonly grown cereal straws such as wheat, barley and oats appear to be the most promising source of fiber. In 2012, the United States produced 67.5 million metric tons of wheat, barley, and oats, with about 92 percent of production accounted for by wheat (USDA 2014). Canada's production of these three grains was 48.4 million metric tons, 77% of which was wheat (Statistics Canada 2014).

An estimate of 1.0 ton of straw per ton of grain is commonly used for wheat and other cereal grain crops.[12] Much of the volume of crop residues is not readily or appropriately available for new uses. Some is already being harvested, baled, and used to feed livestock. In other cases, livestock is grazed on fields in the several months directly following the grain harvest. It is also estimated that about one-half of the straw produced in North America is appropriately left on the field for soil conservation purposes (USDA 1994, Wong 1997). In straw-rich regions, soil conservation and various agricultural uses may, together, account for about 60 percent of the total straw produced, leaving a potential average of 40 percent available for other uses. However, in dry producing regions, such as much of Colorado, soil conservation concerns may dictate no straw harvest (Gupta et al. 1979; Lindstrom et al. 1979; Shanahan et al. 1999). In addition, straw yields vary by growing season, with markedly lower production in abnormally dry years.[13]

[12] The ratio of wheat straw to grain production has been estimated by a number of investigators. Such estimates approximate 1.3 tons of wheat straw per ton of grain, 1.0 ton of barley straw per ton of grain, and 1.2 tons of oats straw per ton of grain. When geographic differences are considered, and assuming that less than 100 percent recovery can be attained, estimates of straw yield are often adjusted to more conservative values than those cited above. For example, the Alberta Department of Agriculture (2000) estimates residue volumes more conservatively, reflecting geographic differences and an assumption of only 80 percent recovery. Their estimate is 40 to 80 pounds (18 to 36 kg) per bushel for wheat, and 30 to 45 pounds (14 to 20 kg) per bushel for barley and oats; these numbers convert to 0.6 to 1.2 tons of straw per ton of grain for wheat, 0.6 to 0.9 tons of straw per ton of grain for barley, and 0.9 to 1.4 tons of straw per ton of grain for oats. Another estimate from the grain-producing provinces of Canada and from the western United States, as reported by Wong (1997), suggests production of from 0.8 to 1.8 mt of straw per mt of cereal grain produced. Herein, we have used a conservative figure of 1.0 mt of straw per mt of grain.

[13] For example, Russell (1996) reports that in Montana, about 30 percent of the time straw production is less than one-half of average production.

Even considering these caveats, there is a potential significant volume of available straw. For example, assuming a straw yield of 15 percent from all wheat growing areas in the U.S. and Canada, equates to an estimated 17.4 million metric tons of annual straw yield in the U.S. and Canada (Table 2). To put these volumes in perspective, the 10.1 million ton estimated straw yield for the U.S. is equivalent to about 12% of U.S. pulpwood production in 2011. Similarly, the 7.3 million ton figure for Canada amounts to about 43% of domestic pulpwood production in that same year.

Table 2
Estimated Annual Available Straw Yield in the U.S. and Canada

		Million metric tons		
		U.S.	Canada	U.S./Canada
Production - wheat, barley, oats	100% *	67.5	48.4	115.9
Soil conservation	50%	33.8	24.2	58.0
Agricultural uses	35%	23.6	16.9	40.5
Available Straw Yield	15%	10.1	7.3	17.4

* Assuming 1 mt of straw for each mt of grain produced.

Plastic Paper

Currently, paper made of polypropylene or polyester (plastic paper) is being advertised as a 100% tree-free, green alternative that purportedly results in conservation of forests, water, and natural resources (Yupo 2014). The raw material for these plastics is petroleum. Considering all plastic products, plastic feedstocks account for about 4 percent of world oil production directly, with another 4 percent used in plastic products production (Thompson et al. 2009). Production of plastics carries huge environmental costs, with markedly greater impact than wood-derived paper in almost every impact indicator, especially fossil fuel depletion, global warming potential, and the full range of other impact indicators linked to fossil fuel use. Thus, any significant production of plastic paper products would serve to increase fossil fuel consumption and plastics use substantially – a doubtful environmental objective no matter what other factors may be at play.

Tree-free Paper: Examining Environmental Impacts

Every step in planting, nurturing, tending, harvesting, collecting, transporting, and processing results in environmental impacts – whether involving trees, fiber crops, fossil fuels/plastics, or recovery and recycling of fiber. No raw material is inherently environmentally superior, and because of this it is necessary to systematically think about the steps involved throughout a product's life cycle, using verifiable data wherever possible.

It is sometimes claimed that application of fertilizer, pesticides, and herbicides is not necessary in the production of non-wood fiber crops. However, with a few exceptions, field experience has shown that such applications are common because they greatly increase the growth rates, yields, and economic returns. This topic is discussed in depth in several earlier-cited reports (Bowyer 1999, 2001, 2014). So, while fiber crops offer higher annual fiber yields than forest plantations or naturally managed forests, the quantity and frequency of inputs is also greater. Previously noted large numbers of passes across the landscape associated with production of fiber crops, combined with rapid growth rates, generally result in more frequent use of inputs to stimulate growth and to suppress competition and pests. Site-clearing harvests are, by definition, more frequent in annual cropping systems. Some of these differences are summarized in Table 3.

Table 3
Frequency of Inputs and Harvest Activity for Various Fiber Sources

	No. of fertilizer applications over a 50-yr. period	No. of herbicide applications over a 50-yr. period	No. of pesticide applications over a 50-yr. period	No. of harvest cycles over a 50-yr. period*
Kenaf	100	100	0-50	50
Moso bamboo	16-32	0	50	16-25
Hemp	50	50	0	50
Loblolly pine	0-4	2-4	0-4	1-5
Slash pine	0-4	2-4	0-4	1-5
Aspen	0	0	0	1
White Spruce	0	0	0-4	1

* One site-clearing harvest. Pine stands would typically experience 3-4 additional partial harvests (thinnings) at 9-10-yr. intervals. Aspen and spruce stands may be thinned once toward the middle of the harvest cycle, but in that case would likely have higher annual yields than indicated in Table 1.

Wheat production inputs and harvest activities would be similar to those shown in Table 3 for kenaf or hemp. Wheat straw is not included in Table 3 since it is a co-product of grain production, with allocation of fertilizer, herbicide, and pesticide use dependent upon appropriate allocation rules that consider either the relative mass or value of products and co-products (wheat straw was valued at 20% that of grain in the Kimberly Clark study). Evaluation of overall environmental impact also depends upon the fate of straw if not harvested for use in papermaking. In some regions, where cold soil temperatures prevent breakdown of stalks during winter months, excess straw is burned in order to dispose of it. In this case, environmental impacts of straw production and collection are tempered by emissions avoided by not burning.

Perhaps the most extensive assessment to date of potential environmental impacts linked to purpose-grown agricultural fiber crops was that commissioned by Kimberly Clark (Thomas and Liu 2013). Their evaluation of potential fiber alternatives involved a cradle to grave LCA of:

- three fiber crops (bamboo, kenaf, and Arundo donax);
- fiber from wheat straw;
- comparison of bamboo to non-bleached softwood kraft pulp (NBSK) from Canada, and
- comparison of wheat straw, kenaf, and Arundo donax to recycled fiber.

The scope of the LCA included all processes needed to produce pulp from the various sources, including forestry or agricultural processes, transport from field or forest to the mill, pulping, and end-of-life. Assessment of recycled fiber began at the point of paper collection and extended to end-of-life.

Study results showed that while pulping processes differ by fiber, environmental impacts are broadly similar across fiber types. The comparisons showed lower impact for bamboo than NBSK in most environmental impact categories, in large part due to an assumption that NBSK would be shipped from pulp mills in Canada to mill locations in the southeastern U.S. (current practice), whereas bamboo was assumed to be grown close to mill sites. Report authors placed substantial emphasis on differences in fiber productivity and the resulting reduction in land area dedicated to fiber production when relying on southern-grown bamboo rather than northern-grown spruce. Also cited were differences in harvest-related climate change impacts and the time required to recoup carbon liberated through harvest – both favorable to bamboo. Had the comparisons been between bamboo and southern yellow pine the outcome would likely have

been substantially different given relatively small yield differentials, substantial differences in production inputs, and equalization of transport distances.

One aspect of some of the fiber crops under consideration that arises frequently in the literature, and that was mentioned in the KC study, is invasiveness of some crops. Both bamboo and Arundo donax are classed as invasives, creating a degree of risk should large-scale plantations be established.

Another factor that warrants consideration in paper procurement is the source of fiber used. For example, one tree-free paper sold under the brand name *Wildgrass Paper* is said to be made from "natural abundant and renewable sources of wild grass from the hills mixed with abaca fiber" (Buygreen.com 2014). Understanding environmental impacts of this product would require understanding what kind of grass was used, in what quantity, from which hills, how it was harvested, how frequently, and with what impact on native flora and fauna. Moreover, knowledge of sources of abaca is important. Abaca is a specialty fiber crop grown throughout the humid tropics, with primary supplies produced in the Philippines and Ecuador. Abaca production in Ecuador is generally in highly mechanized plantations. Imported bamboo fiber and paper products originating in China provide another example. While tree-free, such paper is likely to be associated with a large set of impacts as discussed at length in Bowyer et al. (2014). On the other hand, paper made from crop residues such as bagasse, cotton linters, or banana stalks are potentially low impact products, but production methods and key aspects of supply chains are again important determinants of overall environmental impact. As this discussion illustrates, evaluation and comparison of environmental impacts can be complex and is influenced by a large number of variables. An effective environmental assessment relies on having access to a great deal of information regarding the materials used, their sources and production systems.

100% Recycled Fiber

The U.S. recovery rate for all paper and paperboard was 63.5% in 2013 (American Forest and Paper Association 2014). Paper continues to be one of the most recycled materials. Some manufacturers are currently advertising 100% recycled paper as tree-free, but this assertion warrants a second look.

First, it is a near certainty that all of the fiber in a 100% recycled paper product is wood fiber. Second, the reality is that there is a limit to the number of times wood fibers can be recycled. Each time paper is recycled the fibers that make up the paper become progressively frayed and shorter. The result is that after five to seven times through the recycling process, the fibers become unraveled and shortened to the point that new fiber must be added to replace them. As explained by Metafore (2006) *"To make the global fiber supply work, a continual input of fresh fiber is needed depending on the grade of paper manufactured (from 34% for tissue to 89% for printing and writing papers). Without this continual addition of fresh fiber, the supply of usable recycled fiber available to manufacture new products would last only a few months, depending on the grade of paper being manufactured (from 1.5 months for printing and writing papers to 17.5 months for tissue)."* Thus consumption and collection of paper with virgin content is needed to generate recycled materials that can be used in paper labeled with 100% recycled content.

Will Harvesting Fewer Trees Lead to Growing More Forests?

An underlying assumption in promotion of tree-free paper seems to be that reduced use of wood for pulp production would 'save' trees, and therefore result in more trees and perhaps a greater extent of forests.[14] It is worth considering whether this proposition is realistic.

An important factor in understanding how the use of wood relates to the growing of forests is the fact that virtually all pulpwood (89%) harvested in the U.S. comes from private land (USDA-Forest Service 2012). About 445 million acres of forestland is privately owned in the U.S. This is 57% of all forest land, and an area larger than the twenty-three eastern-most states combined.[15] Similarly, the U.S. has about 408 million acres of cropland,[16] also primarily privately owned. It is well recognized that policies and markets directly influence what is grown on America's private farmlands. Strong markets for corn, soybeans and cotton result in more acres growing those crops. Similar factors – policies and markets – influence America's private forestlands.

Many forest landowners manage their lands for wildlife benefits, recreation opportunities and other objectives and do not necessarily view timber harvest as a *primary* objective of forest ownership; however, most forest owners do harvest timber when there is an opportunity to do so. Significant numbers of landowners practice timber harvesting as an important source of household income.[17]

So how might forest owners react to a loss of markets and income that could result from reduced harvests of pulpwood? McCraw (2014) noted that conversion of pastures, grasslands and forestland to cropland is a current reality in the face of record corn prices. In his words: "Keep in mind that there is no such thing as marginal farmland. Marginal farmland in the South is called timberland."

Another problem is the potential for conversion of forestland due to urban expansion and other developed uses, a problem that can be accentuated by reduction in forestland value through loss of markets for wood products. Lubowski et al. (2007) reported that shifts in land uses such as from agriculture to forestry and vice-versa are quite common and driven by factors ranging from population growth and local tax policy, to timber and crop prices and subsidies. With respect to forestland in particular, Lubowski and colleagues commented on increases in forestland area that occurred between 1982 and 1997, pointing out that increases in timber net returns were the most important factor for the increase in forest area. This trend has continued to the present. However, a recent U.S. Forest Service assessment (2012) indicates the potential for losses in the southern region of as much as 21 million acres of forestland by 2060 due to land conversion primarily associated with urbanization and infrastructure development.

[14] Similar assumptions are also associated with the promotion of electronic billing and other services that avoid the use of paper.

[15] 445 million acres is equivalent to approximately 695,000 square miles, an area larger than Alabama, Connecticut, Delaware, Florida, Georgia, Indiana, Kentucky, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont, Virginia, and West Virginia combined.

[16] http://www.ers.usda.gov/datafiles/Major_Land_Uses/Total_land/Cropland/Cropland_19452007_by_state.xls

[17] For more information about America's woodland owners, their management objectives, rate of harvest, and other data, visit: http://www.fia.fs.fed.us/nwos/ to view the National Woodland Owner Survey results. For the report of results, visit: http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs27.pdf

Looking more broadly at the question of whether reducing demand for forest products is likely to result in greater forest area and more trees, a number of investigators have suggested just the opposite – that efforts to protect forests primarily through non-market forces could, in fact, result in forest loss. Over 50 years ago Dawkins (1958), as part of a discussion about whether plantation establishment might serve to take pressure off natural forests, wrote "Even where plantations are justified, it does not necessarily follow that all remaining naturally regenerated forests are best left unproductive. If they are, they may become vulnerable to destruction . . ." Subsequently, Sedjo and Botkin (1997) gained a great deal of attention from the observation that society could produce all the wood it wanted on very little land dedicated to high-yield plantations. Less noticed was their caution that it is not necessarily a good idea to prevent any harvesting in native forests. Whitmore (1999), who worked extensively in the world's tropical forests, echoed this theme, stating that although plantations can diminish pressure on native forests, native forests should, nonetheless, continue to be managed extensively. The reasoning behind these admonitions is similar to that articulated by a broad group of industry, government, and environmental leaders convened by Thomas Lovejoy (1990), then Assistant Secretary for Environmental and External Affairs for the Smithsonian Institution – namely that if the value of forests is diminished, the value of the land occupied by forests is diminished as well, making conversion to agriculture or other uses more likely.

Ince (2010) examined this issue by looking broadly at various global regions and the wood use and forest trends within them. His findings, summarized below, are consistent with earlier observations about a direct link between wood use and forest sustainability:

- Industrial roundwood harvest levels in North America and Europe are by far the highest among global regions.
- North America and Europe are the only global regions experiencing net sequestration of carbon in forests and in aggregate a positive net change in forest area.
- High levels of industrial timber harvest are coincident with fairly stable forest cover trends.

It may well be, then, that the very foundation of the tree-free movement is flawed. Counter intuitively, continued use of paper and other wood products may be a key factor in maintaining a forested landscape for future generations. This realization is reflected in today's third-party forest certification systems that aim to offer a market-based system for supporting the sustainable growth, harvesting, and consumption of forest products.[18]

The Bottom Line

Paper can be produced from a wide variety of raw materials. Though wood has generally been found to be the most cost-effective source of fiber, non-wood fiber has long been used in papermaking in some parts of the world, and some non-wood use continues today.

It is important to recognize that production, collection, transport, and use of all raw materials result in environmental impacts. Fully understanding supply chains is critical to determining environmental attributes of any product. Such analysis reveals that wood-based and tree-free papers alike are associated with environmental impacts. Some fibers, such as from crop residues or thinnings from sawtimber management, represent low impact options when viewed as by-

[18] For example, see: http://welcome.fsc.org/our-global-impact.8.htm

products and their environmental impacts are attributed to the primary food or timber crop they are derived from. Other potential papermaking materials, such as plastics, are high impact options because they are derived from non-renewable, fossil fuel-based resources.

While saving trees and protecting forests is a widely shared goal, avoiding the use of wood is not necessarily the way to get there. It is precisely the areas of the world that consume the least wood that continue to experience the greatest forest loss.

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