Industrial Hemp (Cannabis sativa L.) as a Papermaking Raw Material in Minnesota: Technical, Economic, and Environmental Considerations[1]

by

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Abstract

Consumption of wood is increasing worldwide as demand for paper, structural and non-structural panels, and other products rise in response to population and economic growth. Interest in alternative sources of fiber is increasing as concerns about the adequacy of future supplies of wood fiber are growing.

One potential source of industrial fiber is agricultural crops, either in the form of residues of food crops or plants grown specifically for fiber. One species that has generated interest as a fiber source is industrial hemp (*Cannabis sativa* L.). This report focuses on the potential use of industrial hemp as a source of paper making raw material in Minnesota. Environmental implications of commercial scale hemp production are also examined.

Hemp has a number of properties that favor its use as a papermaking raw material. About one-third of the fiber of the hemp stalk, that from the outer layers or "bark," is quite long, a desirable quality for developing high-strength paper. Also, the proportion of lignin throughout the stalk is lower than in wood, a property that favors high pulp yields. Fiber from hemp bark has also been found by a number of researchers to be an acceptable raw material for use in contemporary papermaking, and it appears that hemp paper could be manufactured at a competitive price to paper made of wood pulp.

Despite the seemingly promising outlook for industrial hemp as a papermaking raw material, there are several issues that must be addressed if hemp is to become a viable fiber source in Minnesota. Among these are persistent problems related to economical bark/core separation, long-term fiber storage following harvest, and potential issues related to ongoing large-scale agricultural production of hemp. Other issues arise from the fact that hemp core fiber, which comprises 65 to 70 percent of stalk volume, has markedly different properties than hemp bark fiber, and generally less desirable properties than even the juvenile fiber of wood.

From an environmental perspective it makes little sense to promote the use of hemp over fiber produced in intensively managed forests or forest plantations. Although a given area of land will generally produce a greater quantity of hemp than of wood fiber, the fact that hemp is an annual crop requiring relatively intensive inputs, as compared to trees that are managed less intensively over longer harvest cycles, translates to substantial overall environmental impact from hemp production.

Context

Expanding Paper Demand

The global paper industry, as well as that of the United States, has enjoyed an extended period of rapidly rising demand (Table 1). Globally, consumption of paper and paperboard has expanded to more than 8.5 times 1950 levels, a period in which the world population expanded by 2.4 times. Growth in U.S. paper consumption has also been dramatic. Total U.S. paper consumption at the beginning of the new millenium is now four times that of 1950; the population of the United States grew by just over 86 percent during that 50-year period. Domestic demand for paper and paperboard is likely to rise 50 percent or more by 2050.

Growing paper demand is important to Minnesota in at least two ways:

- Demand for paper is increasing steadily in Minnesota with continued growth in the population and economy. Assuming the same per capita use of paper in Minnesota as nationally, paper consumption by Minnesota residents has increased four times since 1950. Considering the medium projection of population growth for the century ahead (U.S. Census Bureau, 2001), it is likely that paper demand will double again within Minnesota by the year 2100.
- Paper production is important to Minnesota's economy, and particularly the economy of Greater Minnesota. The current $4+ billion industry provides well-compensated employment to tens of thousands of industry employees and suppliers, as well as significant tax revenues to state and local government.

Table 1

U.S. and Worldwide Pulp and Paper Consumption vs. Population - 1950 to 2000

	United States			World		
Year	Consumpt. of paper & paperboard[a] (million mt)	Av. ann. inc. in paper consumpt. for prev. 10 yr. (%)	Ann. pop. growth rate[b] for prev. 10 yr. (%)	Consumpt. of paper and paperboard[c] (million mt)	Av. ann. inc. in paper consumpt. for prev. 10 yr. (%)	Ann. pop. growth rate for prev. 10 yr[d] (%)
1950	22			38		
1960	31	4.5	1.7	77	7.3	1.7
1970	48	4.5	1.2	128	5.5	2.0
1980	59	2.1	1.1	170	3.1	1.8
1990	78	2.8	1.0	240	3.5	1.7
2000	96	2.3[e]	1.0[e]	317	3.1[e]	1.4[e]
2010	113	1.5	0.8	440	3.3	1.2

[a] Figures for 1950 and 1960 from the American Paper Institute (1984). More recent data from American Forest & Paper Association. Recovered Paper Statistical Highlights- 2000 Edition.
[b] Source: Calculated based on data from U.S. Bureau of the Census, U.S. Popclock Projection. 2001. http://www.census.gov/cgi-bin/popclock
[c] Source: FAO. 2001. Forestry Statistical Database. http://www.fao.org
[d] Source: U.S. Census Bureau, World Population Statistics (http://www.census.gov/ipc/www.worldpop.html)
[e] For previous 9-year period.
[f] FAO (1993)

The fiber supply situation in Minnesota is, however, becoming a limiting factor to industrial growth, as it is worldwide. John Krantz, the chief wood utilization specialist with the Minnesota Department of Natural Resources, recently commented on the Minnesota fiber supply situation, noting that while increased forest growth rates over the longer term will likely sustain current and planned harvest rates, the outlook in the relatively near term is less certain. A widely reported aspen age-class-imbalance could cause wood supply disruptions within the next several decades that could conceivably lead to closure of one or more oriented strandboard (OSB) mills (Krantz 2001).

Kaldor (1992) noted almost a decade ago that the combined effect of past and projected increases in paper demand could lead to a global shortage of virgin fiber shortly after the turn of the century. He further estimated that if future needs for papermaking fiber were to be met using wood fiber, approximately 25 million acres of tree plantations per year would have to be established beginning "now." Although Kaldor assumed 10-15 year cutting cycles in his calculations, rather than 4-5 year cycles now viewed as optimum for intensively managed plantations of fast growing hardwoods, it is nonetheless clear that concerted actions will be needed to ensure future supplies of fiber. Bold initiatives, including development of non-forest fiber sources, will likely be necessary to ensure sufficient industrial fiber for the future.

Increasing Pressures on Forests

Not only is demand for paper rising in response to population and economic growth, but increasing population is also steadily reducing the area of forest land on a per capita basis. The historical record in this regard is dramatic (Tables 2 and 3). The U.S. currently has 2.7 acres of forest for each of its citizens. Worldwide, the current forest area is 1.4 acres per capita. Taking into account projected U.S. and global population for the year 2100 yields sobering numbers. By the end of this century it appears that the U.S. will have only 1.3 acres of forestland per capita. Globally, the average will be only about 0.7 acres. Moreover, these figures include *all* forestland; the area available for periodic harvest of timber will obviously be even less.

Will this kind of per-capita reduction in forestland allow wood production to keep pace with increases in population? A 1990 analysis by Sedjo and Lyon (1990) presented a very optimistic view regarding adequacy of future wood supplies. A key conclusion of that analysis was that dramatic increases in industrial wood demand within developing nations was unlikely, primarily due to large foreign debt burdens. Moreover, technological advances in growing and processing wood were expected to stretch the wood supply. Nonetheless, recent trends suggest that continued investment and technological development will be necessary to ensure that wood production will rise at a sufficient rate to keep pace with population growth.

Table 2
Historical and Projected U.S. Forest Area Per Capita – 1785-2100

Year	Population[a/]	Forest Area (million acres[b/])	Forest Area/Capita (million acres)
1785	3,000,000	1,044	348
1850	23,300,000	926	40
1910	77,000,000	730	9.5
2000	274,000,000	737	2.7
2100	571,000,000	737	1.3

[a/] U.S. Census Bureau, 2001. http://www.census.gov/cgi-bin/popclock/
[b/] Powell et al. (1993)

Table 3
Historical and Projected World Forest Area Per Capita – 1800-2100

Year	Population[a/]	Forest Area		Forest Area/Capita	
		billion ac.	million ha.[b/]	acres	hectares[c/]
1800	1 billion	11	4.5	11	4.5
2000	6.1 billion	8.5	3.4	1.4	0.6
2100	10-11 billion	8.5	3.4	0.7-0.8	0.3

[a/] U.S. Census Bureau. 2001. http://www.census.gov/cgi-bin/ipc/popclockw
[b/] Brown and Ball (2000)
[c/] One hectare = 2.47 acres.

U.S. Forest Service figures for 1992 show average annual growth per acre for all timberland[1] in the United States to be 44.2 ft^3; the highest average rate of growth reported by ownership type was on industrial land, where annual growth was estimated at 60.9 ft^3 per acre. Global figures from FAO are less precise due to the enormity of the data collection challenge, but recent estimates of annual growth and total forest area suggest an average annual growth globally of 23.9 ft^3/acre for unmanaged natural forests. The global growth estimate includes all forestland, and not commercial forestland only as in the U.S. figures.

The average U.S. resident consumes 64.5 ft^3 of roundwood annually (Howard 1999). Worldwide, this figure is 21.2 ft^3. Using the current annual growth figures for the U.S. and the world in combination with consumption numbers indicates that each U.S. resident requires 1.5 acres of forest to provide annual wood needs and that each global citizen

[1] Only those lands capable of producing 20 ft.3/acre/year and on which periodic harvest is not prohibited by law are included in the timberland figure. In 1992 some 489,555 thousand acres of the total 736,681thousand forested acres in the United States were included in the timberland category.

requires 0.91 acres. Yet, the *total* area of forest per capita by the year 2100 is expected to be 1.3 acres and 0.74 acres for the U.S. and world, respectively (Table 4). If it is assumed that only two-thirds of the total forest area is available for periodic harvest, then the area of harvestable forest per capita by the year 2100 becomes even less - 0.87 acres for the U.S., and 0.5 acres for the world as a whole. The net effect of these various factors is that supplying global needs for wood and fiber is becoming increasingly problematic.

Table 4
A Comparison of Annual Per-capita Wood Consumption and Available Forest Area to Support That Consumption - 2000 and 2100

		United States	World
Net annual forest growth (average)	ft^3/acre	44.2	23.9
Per capita consumption of wood (annual)	ft^3	64.5 [1/]	21.7
Forest area needed/capita to supply wood needs	acres	1.5	0.91
Forest area/capita - 2000	Acres	2.7	1.4
Forest area/capita - 2100	Acres	1.3	0.7

[1/] Ince (2000)

Minnesota is not immune to these kinds of problems. Population growth in combination with clearing of forests for a variety of reasons has reduced the area of forests on a per capita basis both indirectly and directly over the past five decades. An indirect impact of population growth has been the loss of about 15 percent of the forested area in Minnesota, almost totally due to urban expansion, over the past fifty years. Over the same time period, Minnesota's population has grown from 2.99 million to just under 5 million. The combined effect of these developments is that the forest area in Minnesota declined from 5.7 acres per capita in 1950 to 3.1 today. Projected population growth over the next century is likely to further reduce the area of forest per capita within Minnesota to only 1.6 acres, even assuming no further loss of Minnesota forests. As with the world and the United States as a whole, the steady decline of forests on a per capita basis, in combination with steady growth in demand for paper and other wood products, will make procurement of adequate supplies of wood and wood fiber more and more challenging in the decades to come.

One solution to this problem could be to increase the intensity of management in the world's natural forests, an option that is technically quite possible since only a fraction of the world's forests are actively managed using modern forest management tools. However, an increase in management intensity in domestic and global forests today appears unlikely; societal pressures are leading to increased areas of forest reserves and a lower intensity of management on those lands that are managed for timber production.

Other solutions to potential fiber supply problems might involve efforts to increase the area of forest plantations within Minnesota, the U.S., and globally, to expand recycling activity, to develop technology for using agricultural crop residues, or perhaps to move toward reliance on annual fiber crops, such as industrial hemp, as a source of industrial fiber.

Increasing the Area of Forest Plantations

Absent of a general increase in forest management intensity, an option for increasing the wood supply that has received a great deal of attention in recent decades is establishment of vast areas of high-yield forest plantations. The potential for increased wood production in such plantations is great. Currently, plantation forests comprise only about 4.2 percent of forests globally (up from 3.5 percent in 1995), but provide 21 to 22 percent of industrial wood (including approximately 20 percent of pulpwood), 4 percent of fuelwood, and 12 to 13 percent of annual wood production overall. Forest plantations were estimated to cover about 306 million acres globally in 1995. The current rate of establishment of such plantations is rapid (11 to 12 million acres/year) (Brown and Ball 2000), and so much so that some are predicting a glut of plantation wood in Asian and world markets by 2010 (Leslie 1999). Additional supplies of wood are likely to result from increased wood production on agricultural lands through expansion of agroforestry systems in many parts of the world (Beer 2000; Simons et al. 2000). Both developments are largely taking place within the developing nations and most significantly in the tropical regions.

Within the United States, plantations are also predicted to supply increasing quantities of wood fiber in the decades ahead. In fact, a recent estimate indicates that increasing volumes of plantation pine in the U.S. Southeast will provide sufficient pulpwood to provide for expected growth of the domestic paper industry through at least 2050 (Ince 2001).

Despite the high current rate of forest plantation establishment, Sutton (1999) reports that there is a significant gap between what society appears willing to have produced in natural forests, and what an extension of current wood demand trends would seem to indicate for future wood consumption. In order for forest plantations to fill the gap will require establishment of about 250 million acres of high-yield plantations by the end of this century beyond what exists today. Sutton points out that planting on this scale would require a huge global effort, noting that "it would require most of the world's land that is suitable for planted forests and which currently is surplus to food production, but which is not already in forest." Brown and Ball (2000) recently examined several scenarios for creating new forest plantations, and concluded that establishment of 250 million acres of new plantations is "generally achievable in physical terms," requiring continuation of the 1995 planting rate through 2010 and a declining planting trend thereafter through 2050.

In monetary terms, an investment on the order of US $100 to $150 billion will be needed to create 250 million additional acres of plantations worldwide. Moreover, should reliance on forest plantations for wood supplies increase to the extent that some have forecast, significant dislocations of the present forest products industry, from developed to developing nations, are likely as manufacturing activity migrates over time to locations close to the raw material base.

Minnesota currently has approximately 16 thousand acres of hybrid poplar plantations (Krantz 2001), and perhaps 80 to 100 thousand acres of red pine plantations. While the productivity of these plantations is considerably lower than the most productive hardwood and softwood plantations globally, these stands are nonetheless currently important to Minnesota's wood supply, and even absent of additional plantation acreage, the relative importance of plantations is likely to increase in Minnesota in the decades ahead

Expansion of Recycling Activity

Increases in paper recycling over the past half-century have clearly served to reduce the consumption of virgin pulpwood in comparison to what consumption would have been in the absence of heightened recycling activity. Further expansion of recycling will further extend raw material supplies. However, recycling alone will not solve the potential wood fiber supply problem described above. Consideration of the current paper recycling situation in the United States provides a good example of the likely benefits and limitations of increased paper recycling.

In 2000, 45.0 percent of all paper used in the United States was collected for reuse. This amounted to 47.3 million tons of recovered paper. Recovered paper provided 37.8 percent of the U.S. paper industry's fiber in 2000 (AF&PA 2001). The difference between the wastepaper collection rate (45.0 percent) and the recovered paper use rate (37.8 percent) is largely traceable to the fact that the United States is the world's largest exporter of waste paper.

While paper recycling is extremely important, and a major contributor to reducing demand for virgin pulpwood over the past several decades, it is important to recognize that increasing recycling activity represents only one component of the fiber supply equation for the future. For example, if paper recycling in the United States were to be suddenly increased to the maximum level allowed by current technology (about 65 percent recycled content) this would have the effect of reducing demand for virgin fiber by only 12 to 13 percent. Moreover, when taking into consideration the time that will likely be required to move to the technological limit of recycling, and the population growth that will occur in the meantime, it is highly probable that demand for virgin fiber will continue to increase, even with aggressive recycling programs. Therefore, increased paper recycling alone will not be sufficient to ensure adequate fiber supplies in the future.

Potential Use of Agricultural Crop Residues

Fiber from agricultural crops has long been used for a variety of purposes, including fuel and a source of papermaking fiber. For example, paper was invented in China in A.D. 105, but it was not until about 1850 that wood began to be used as a principal raw material for papermaking. Early sources of fiber included flax, hemp, bamboo, various grasses, cereal straw, cottonseed hair, leaves, and inner bark of trees (Isenberg 1962, Miller 1965).

Wheat straw chemical pulp was first produced in 1827 (Moore 1996). Crop residues, such as bagasse (or sugarcane residue), have long been used in making paper in China, India, Pakistan, Mexico, Brazil and a number of other countries (Pande 1998). Today, production of paper and paperboard from crop residues is on the rise, with the percentage of pulp capacity accounted for by non-wood fiber globally now close to 12 percent; this compares to an estimated 6.7 percent non-wood fiber in 1970. Wheat straw is currently estimated to account for over 40 percent of non-wood fibers, with bagasse and bamboo together accounting for another 25 percent (Atchison 1996).

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 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. Today, however, new research is focused on potential development of agricultural residue-based paper technology and industry development (Alcaide 1993; Jewell 1999).

In 1996, the Paper Task Force, a group of paper industry experts convened under the auspices of the Environmental Defense Fund and Duke University, and funded by several large U.S. corporations 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) that technology improvements are likely to improve pulp properties and reduce pulping costs, 3) that 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) that the most likely use of straw pulp was as an additive to wood pulp. Overall, the outlook regarding use of straw pulp was positive.

Any consideration of the quantity of crop residues that might be available for pulp and paper production must recognize that agricultural residues are also being actively evaluated as a potential source of raw materials for bio-based energy production and for manufacture of structural and non-structural panels. Although a wide variety of crops might provide fiber for the paper industry, commonly grown crops in the U.S. that appear to be the most promising source of fiber are the cereal straws: wheat, barley, and oats. In

1999 the United States produced just under 78 million short tons of wheat, barley, and oats. Approximately 78 percent of production of these three grains was accounted for by wheat. Minnesota produced 2.87 million tons of wheat, barley, and oats in 1999[2] (Minnesota Agricultural Statistics Service 2001).

The ratio of wheat straw to grain production has been estimated by a number of investigators in recent years. 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 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, a figure of 1.0 ton of straw per ton of grain is used is commonly used for wheat and other cereal grain crops.

It is recognized that much of the volume of crop residues is not available for industrial uses. In North America about one-half of the straw produced is left on the field for soil conservation purposes (U.S. Department of Agriculture 1994; Wong 1997). In addition, some is harvested, baled, and used to feed livestock. In other cases livestock is grazed on fields in the several months directly following the grain harvest. In straw-rich regions, such as northwest Minnesota, soil conservation and various agricultural uses may together account for about 60 percent of the total straw produced, leaving a surplus of 40 percent on average.

How significant, then, is the quantity of straw available for industrial use? A simple calculation reveals the magnitude of the potential resource. Conservatively assuming a straw surplus of 15 percent instead of 40 percent (allowing for cyclical variation in straw production), but also assuming that surplus straw could be gleaned from all of the area on which wheat is produced in Minnesota yields the following estimate:

Estimated surplus straw in Minnesota - 1999:

		(million tons)
Wheat, barley, oats (100%)[a/]		2.871
Soil conservation	(50%)	1.436
Agricultural uses	(35%)	1.005
Surplus	(15%)	0.430

[a/] assuming 1mt of straw for each mt of grain produced.

Based on total small grain production in Minnesota in 1999, the approximate quantity of surplus grain produced in the state was 430 thousand metric tons. This is theoretically

[2] Based on yields expressed in bushels from the Minnesota Agricultural Statistics Service (2001) and weights of 60, 50, and 32 pounds per bushel (@12 percent green wt. Basis moisture content) for wheat, barley, and oats, respectively.

enough to supply the total fiber needs of a paper mill the size of the new Potlatch mill in Cloquet, Minnesota.

Annual Fiber Crops as a Source of Industrial Fiber

There are relatively few recent examples of crops other than trees having been planted specifically for the purpose of providing a source of energy or raw materials for industry. One exception is jute, a crop long cultivated throughout the world to provide the long fibers used in making cloth sacks and cordage.

During World War II the U.S. was cut off from jute fiber suppliers in Asia, triggering a massive effort to develop fast-growing alternative crops, including hemp, and kenaf (*Hibiscus cannabinus* L.), as jute substitutes (Atchison 1996). Hemp was actively promoted by the USDA in the early 1940s as a potential source of strategically critical cordage fiber (Hackleman and Domingo 1943; Robinson and Wright 1941; Wilsie et al. 1942, 1944; Wright 1941, 1942a, 1942b, 1942c, 1943). In fact, the United States government had supported the growing and use of hemp over a period of many decades (Anonymous 1890; Darcy 1921; Dewey 1901, 1913, 1927; Dodge 1897; French 1898; Humphrey 1919; Wright 1918). Although hemp production had been encouraged over many years, significant production of this crop did not occur until the war-related promotion efforts began. In the early 1930s, the total U.S. area planted to hemp varied from only 140 to 700 acres. The area planted doubled in 1936, remaining at 1,400 to 2,000 acres through 1940. Because of the jute shortage and government efforts to promote alternative crops, the acreage planted to hemp increased rapidly after 1940, reaching a peak of 178,000 in 1943 (Ash 1948); 46,000 of these acres were in Minnesota. As soon as the war ended, hemp production dropped dramatically, with the total acreage nationally down to 4,800 by 1946. Ash (1948) reported that hemp was mainly produced in the peak production years of the 1940s in Italy, Russia, Turkey, Yugoslavia, Hungary, China, Japan, Chile, and the United States. Within the U.S., primary producing states were listed as Illinois, Iowa, Indiana, Wisconsin, Kentucky, and Minnesota. As part of the effort to develop alternatives to jute, Cuba and later Guatemala were involved in intensive activity which resulted in development of a number of high yielding varieties of kenaf. It is not clear why kenaf, and not hemp, were the focus of those early efforts. In any event, subsequent work within the U.S., which continued through 1960, led to development of additional varieties of kenaf. Meanwhile, research on and promotion of hemp continued through the early 1950s (Black and Vessel 1945; Fuller et al. 1946a, 1946b; Lewis et al. 1948; Robinson 1952; Vessel and Black 1947)

In an initiative that was at first unrelated to the early work on kenaf, the U.S. Department of Agriculture set about in the mid-1950s to identify crops that could help to expand and diversify markets for American farmers. The idea was to find new fiber crop species that contained major plant constituents different from those then available and to promote their potential for industrial use (McCloskey 1996). It was agreed that work would focus on species that could replace crops in surplus, but not compete with them (Atchison 1996).

Because there was little in the way of historical knowledge from North America or elsewhere in the world to build on regarding industrial raw material crops, the USDA, in 1957, launched a massive crops screening program. As explained by Atchison (1996) " the emphasis was on studying fiber crops that could be used as raw materials for pulp and paper manufacture. More than 1200 samples of fibrous plants from about 400 species were screened, taking into consideration all technical and economic factors involved. Hemp was among the plant species evaluated, although it was dropped from consideration early on in the screening process. 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 fibrous materials: kenaf, crotalaria, okra, sesbania, sorghum, and bamboo." After two more years of intensive work, kenaf emerged as the top candidate for further research into utilization options and technologies (Kugler 1990). How much of this finding was influenced by the earlier work on kenaf is not clear, but in any event the stage was set for a renewed kenaf research effort.

Over the next 15 years kenaf was the focus of intensive research. 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 1978, perhaps concluding that as much had been done in the way of federally sponsored research as was practical, the USDA terminated funding for kenaf research. Atchison (1996) notes that the decision affected not only kenaf research, but agriculturally derived fiber research in general. The USDA Peoria laboratory, for example, dismantled and sold its complete pilot plant facilities for working on non-wood plant fibers shortly after the cut in funding was announced.

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 research on industrial hemp funded by at least four state governments (U.S. Department of Agriculture 2000). Although the new federal effort is focused on potential energy and chemical crops, much of the state-funded research has been directed toward further investigation of the commercial potential of kenaf and of industrial hemp, the latter having been excluded from the earlier USDA alternative crops research. The primary impetus for all of these efforts appears to be the depressed farm economy throughout most of the U.S.

Recent kenaf research has centered on harvesting and breakdown of stalks, technical and economic possibilities of substituting kenaf fiber for wood and other traditional materials in traditional products manufacture, and on development of niche markets. Pulp and paper and structural and non-structural composites are among the products being investigated (Sellers et al. 1999). It appears that progress is being made in all areas of research. Should kenaf emerge from current research and development efforts as a viable source of industrial fiber, it is farmers in the U.S. southeast, central, and northwestern coastal regions who stand to benefit. Because this crop is not suited for very cold climates (it can be grown as far north as southern Illinois), its further development would have only an indirect impact on Minnesota agriculture; an indirect impact could arise from the fact that kenaf crop yields are typically greater than those of hemp.

Investigation of industrial hemp has proceeded more slowly than of kenaf, in part because of the legal hazards and social stigma associated with marijuana, a different but closely related plant; in this case, most research and pilot studies are occurring in countries other than the United States, including Canada, France, and the Netherlands.

Hemp as an Industrial Fiber

The Nature of Hemp

Hemp is a herbaceous annual plant with a single, straight, unbranched hollow stem that grows over a 4 to 5 month growing season to a height of about one to five meters (3 to 19 feet) and a diameter of 10-60 millimeters (0.4 to 2.3 inches) (Robinson 1943; Ehrensing 1998). The stem is characterized by a relatively thin outer layer (referred to as bark or bast), and a wood-like core that surrounds a hollow center. The bast constitutes, on average, about 30 to 35 percent of the dry weight of the stem (De Groot et al.1999; Zomers et al. 1995), with the proportion of bark variously reported from 12 to 48 percent (Van der Werf 1994; Atchison 1998). The Paper Task Force (1996) estimated the bast fiber percentage at 30 percent. Primary bast fibers are highly variable in length, ranging from 10 to 100 mm (0.4 inch to 4 inches), with an average length of 20 to 40 mm. These fibers are thick-walled and rigid. Secondary bast fibers are reported as extremely short: about 2 mm or about 0.1 inch in length. The woody core makes up the remaining 65 to 70 percent of stem weight, and consists of short fibers that are reportedly a rather constant 0.50 to 0.55 mm in length (Table 5). These fibers are significantly shorter than even the juvenile fibers of most hardwood and softwood species.

Chemically, the bark fibers of the hemp stalk contain considerably more cellulose and holocellulose, and significantly less lignin than either hardwoods or softwoods. Hemp core, on the other hand, contains less cellulose than wood, about the same holocellulose fraction, and generally the same lignin content as hardwood species.

No definitive information regarding extractive or ash content of ash could be found in the literature. However, the ash content of kenaf, has been found to be about four times that of wood (Bowyer 1999). Regarding extractive content, although values have not been reported by contemporary researchers, an early report regarding hemp production suggests that this may be high. Robinson (1943) reported that " . . . during the process of retting [involving field aging of harvested stalks] the plants lost about 20 percent in weight in soluble and decomposed materials which leach out . . ."

Table 5

Physical Characteristics of Hemp and Wood

Characteristic	Hemp Bark Primary	Hemp Bark Secondary	Hemp Core	Softwood	Hardwood
Fiber length (mm)	10-100[a] (20)	2[a]	0.55[a]	2.5-5.5[b]	0.8-1.9[b,c]
Juvenile fiber length (mm)				1.3-3.0[d]	0.8-1.3[e]
Alpha cellulose[f]	$67^{+}/-5$[a,g,h]		$38^{+}/-2$[a,g,h]	$42^{+}/-2$[i]	$45^{+}/-2$[i]
Holocellulose[f]	$80^{+}/-1$[a,g,h]		$69^{+}/-3$[a,g,h]	$69^{+}/-4$[i]	$75^{+}/-7$[i]
Lignin[f]	$4^{+}/-2$[a,g,h]		$20^{+}/-2$[a,g,h]	$28^{+}/-3$[i]	$20^{+}/-4$[i]
Extractives[f]				$3^{+}/-2$[i]	$5^{+}/-3$[i]
Ash content[f]				<0.5[i]	<0.5[i]

a De Meijer (1994)
b Panshin and deZeeuw (1980)
c Manwiller (1974)
d Haygreen and Bowyer (1996)
e Koch (1985)
f Expressed as a percentage of the dry weight
g Ranalli (1999)
h Kirby (1963)
i Thomas (1977)

The Narcotic Issue

As noted in a recent USDA report (USDA 2000), industrial hemp contains less than one-percent THC (delta-9-tetrahydrocannabinol), the psychoactive ingredient of marijuana. Varieties of industrial hemp currently cultivated in various countries generally contain 0.3 percent THC or less. In contrast, hemp grown primarily to obtain marijuana contain 1 to 2 percent THC (unselected strains) (Clarke and Pate 1994) to as much as 10 to 15 percent THC in the best modern varieties (USDA 2000; Clarke and Pate 1994). Thus, while it is technically possible to produce marijuana from industrial hemp, it is unlikely to be economical to do so.

The primary marijuana-related issue regarding the possibility of industrial hemp production is that marijuana and industrial hemp plants are distinguishable from one another only through chemical analysis (USDA 2000). The significance of this is that current marijuana interdiction activities of law enforcement agencies would become extremely difficult to impossible should growing of hemp become widespread . Therefore, legalization of industrial hemp production in Minnesota would effectively mean tacit approval of marijuana production within Minnesota as well.

Production of Industrial Hemp

Growth and Yield

Reported yields for hemp grown worldwide are highly variable, reflecting differences in plant varieties and climate. Shown in Table 6 are yields as reported in a number of studies conducted over the past 80 years. It is important to recognize that the highest yields are attainable only on the best agricultural land, and often only with intensive inputs. As Robinson (1943) put it "Hemp should be planted on the most productive land on the farmland that would make 50 to 70 bushels of corn per acre."

Comparisons of annual hemp yields with annual yields of wood in Minnesota stands of *Populus* species (Table 7) shows that reported annual production of dry biomass per hectare or per acre is roughly equal for hemp grown in various locations of the U.S. (1.1-4.0 t/ac./yr. - average 2.4 t/ac./yr.) and for *Populus* tree species grown in Minnesota and Wisconsin (1.4-7.4 t/ac./yr. - average 3.1 t/ac./yr.). Dry yields of hemp stalk and wood are also approximately equal, with average hemp and *Populus* yields reported at 2.2 and 2.0 t/ac./yr., respectively.

It could be argued that the reported hemp yields all occurred five decades or more ago, while the reported wood yields are much more recent. When Minnesota/Wisconsin poplar yields are compared to all hemp yields reported in Table 6, then annual hemp yields exceed wood yields by 70 percent.

Atchison (1998) urged caution when considering reported hemp yields, noting that yields obtained in practice are often lower than those obtained in controlled field trials. In Atchison's words " . . . in my review of the literature, I find that the maximum yield of dry hemp stalk, obtained anywhere commercially, amounted to about 3.0 tons/acre and of this amount, the hemp bast fiber represented only 750 kg/acre or only 25 % of the total dry weight. This was in Germany, where very little hemp is grown. However, in the U.S., the maximum commercial annual yield of dry hemp stalk obtained, during 1943 and 1944 when it could be grown legally during World War II, amounted to only about 1.98 metric tons/acre, of which only 495 kg/acre was bast fiber."

Tempering yield studies of the mid-20th century are more recent reports such as that of De Meijer (1993) who noted sufficient variation within *Cannabis* to allow genetic improvement leading to better yield and quality of fiber. He also indicated the possibility of breeding to improve resistance to pests. Hennink (1994) reported that heritability of bast fiber content is high, raising the possibility of increasing relative yield of this stalk component; he also found that bast fiber content is positively related to stem yield overall.

It is interesting to note that reported industrial hemp yields are significantly lower than reported yields of kenaf. In contrast to the figures indicated above, kenaf stalk yields of about 14 mt/ha (6.3 tons/acre) have been widely reported, placing average kenaf stalk yields at almost double those of hemp. This differential could severely disadvantage hemp producers should kenaf production become common in the United States.

Table 6

Reported HempYields By Location

Location	Combined mt/ha	Combined t/ac	Stalk mt/ha	Stalk t/ac	Leaf mt/ha	Leaf t/ac
	Dry Basis Yield of Biomass[a]					
Holland[b]	**7-10**	3.1-4.5	**4.5-7**	2.0-3.1	**1.4-2**	0.6-0.9
Holland[c]	**8.7-18.4 (14.9)**	3.9-8.2 (6.6)	**7.6-15.4 (12.7)**	3.4-6.9 (5.7)	1.5-3.1 (2.5)	0.7-1.4 (1.1)
Denmark[d]	**7.9**	3.5	7.0	3.1	0.9	0.4
Denmark[e]	**8.9**	**4.0**	8.0	3.6	0.9	0.4
Poland[d]	**6- 8**	2.7-3.6	5.3- 7.1	2.4 -3.2	0.7-0.9	0.3-0.4
France[d]	**7.9**	3.5	7.0	3.1	0.9	0.4
Italy[d]	**13**	5.8	11.6	5.2	1.4	0.6
Italy[e]	**15**	**6.7**	13.4	6.0	1.6	0.7
Netherlands[d]	**9-11.4**	4.0-5.1	8.0-10.1	3.6-4.5	1.0-1.3	0.4-0.6
Netherlands[d]	**10.5**	4.7	9.3	4.1	1.2	0.5
Netherlands[e]	**19.4**	**8.7**	17.3	7.7	2.1	0.9
Netherlands[e]	**9.4-13.6**	**4.2-6.1**	8.4-12.1	3.7-5.4	1.0-1.5	0.4-0.7
Netherlands[f]	**11.9-13.6**	5.3-6.1	10.6-12.1	4.7-5.4	1.3-1.5	0.6-0.7
Germany[e]	**3-10**	**1.3-4.5**	2.7 - 8.9	1.2-4.0	0.3-1.1	0.1-0.5
Sweden[e]	**8.7**	**3.8**	7.7	3.4	1.0	0.4
UK[e]	**5 - 7**	**2.2-3.0**	4.5 - 6.2	2.0-2.8	0.5-0.8	0.2-0.4
Canada[e]	5.6-6.7	**2.5-3.0**	5.0 - 6.0	2.2-2.7	0.6-0.7	0.3
U.S.[g]	4.0	**1.8**	3.6	1.6	0.4	0.2
U.S.[h]	4.5-4.9	**2.0-2.2**	4.0 - 4.4	1.8-2.0	0.5-0.6	0.4-0.3
U.S.[i]	4.0	1.8	3.6	**1.6**	0.4	0.2
U.S.[j]	9.0	**4.0 (fert)**	8.0	3.6	1.0	0.4
	5.9	**2.6 (no fert)**	5.2	2.3	0.6	0.3
U.S.[k]	2.4-9.0	**1.1-4.0 (2.3)**	2.2-8.0	1.0-3.6	0.2-1.0	0.1-0.4
U.S.[l]	6.5	2.9	5.9	**2.6**	0.7	0.3
Minnesota[m]	3.5-3.8	1.6-1.7	3.2-3.4	1.4-1.5	0.3-0.4	0.2
Average of Reported Yields	8.7	3.8	7.7	3.4	1.0	0.4
Average of Reported U.S.Yields	5.4	2.4	4.9	2.2	0.5	0.2

[a] Reported values in bold; all other values calculated using standard conversions. When not specifically reported, the stalk was assumed to constitute 89% of the dry weight of total biomass.
[b] Zomers (1995). Combined weight includes inflorescence (fallen leaves).
[c] Van der Werf et al. (1999). Reports of over 17 trials over a period of 6 years. Combined weight includes inflorescence (fallen leaves).
[d] Ranalli (1999). Reported yields from various studies by various researchers.
[e] Ehrensing (1998). Reported yields from various studies by various researchers.
[f] De Meijer et al. (1995). Yield using herbicides.
[g] Atchison (1998)
[h] Robinson (1935)
[i] Ergle et al. (1945)
[j] Jordan et al. (1946). Reported results from four different researchers.
[k] Robinson (1946). Reported results from eight trials in Nebraska, South Dakota, and Iowa.
[l] Wilcox (1943) as reported by Ash (1948). Average of 112 randomly selected farms in Illinois.
[m] Ash (1948). Figures reported included only bast fiber yield (830 pounds per acre in 1943, 900 pounds per acre in 1944). Stalk yields derived by dividing by 0.30 (the bast fiber fraction of the stem).

Table 7

Reported Average Annual Wood and Biomass Yields from Tree Plantations in the Northern Plains

	Dry Basis Yield of Biomass[a,b]							
	Total Biomass		Wood (Xylem)		Bark (Phloem)		Tops, Leaves, Branches	
Location	mt/ha	t/ac	mt/ha	t/ac	mt/ha	t/ac	mt/ha	t/ac
Hardwoods.								
Hybrid Poplar/ND,SD, MN,WI[e]	3.6- 4.0	**1.6-1.8**	2.3- 2.6	1.0-1.2	0.4	0.2	0.9	0.4
Hybrid Poplar/MN,WI, MI[f]	7.5-16.6	**3.3-7.4**	4.9-10.8	2.2-4.8	0.8-1.7	0.4-0.8	1.8-4.1	0.8-1.8
Hybrid Poplar/WI[g]	**6.2-10.4**	2.8-4.6	4.0- 6.8	1.8-3.0	0.6-1.0	0.3-0.5	1.6-2.6	0.7-1.2
Quaking Aspen/MN[h]	3.2- 3.6	1.4-1.6	2.1- 2.3	**0.9-1.0**	0.3-0.4	0.1-0.2	0.8-0.9	0.4
Avg. of reported yields	6.9	3.1	4.6	2.0	0.7	0.3	1.7	0.8
Softwoods								
White spruce/Minnesota[g]	**4.2**	1.9	**2.9**	1.3	**0.6**	0.3	**0.6**	0.3

[a] Unless otherwise reported, bark is assumed to be 15% of total aboveground stem (wood + bark) weight in softwoods and 10% in softwoods.

[b] Unless otherwise reported tops, branches, and leaves are assumed to be 15% of total stem (combined weight) in softwoods, and 25% of total stem weight in hardwoods (Koch 1973; Young et al. 1963, 1965).

[c] Hansen (1992) -- 4-5 year rotation

[d] Ek et al. (1983) -- 3 year rotation

[e] Zavitkovski (1983) -- 9-10 year rotation

[f] Perala and Laidly (1989) -- 11 year rotation

[g] Rauscher (1985) -- 40 year rotation

Site Requirements

Hemp is said to grow best on fertile, well drained, medium-heavy soils and especially well on silty loams, clay loams, and silty clays (Robinson and Wright 1941). The crop is not limited to these kinds of soils, however, and can evidently thrive on a wide variety of soil types (Van der Werf 1994; Ranalli 1999). A soil pH of less than 5 has been reported to unfavorable to hemp production (Van der Werf 1994).

Climate Limitations

Apparently, climate conditions typical of the northern plains are favorable to hemp production, although short growing seasons and late spring frosts can pose risks to hemp producers. Robinson (1943) and Ree (1996) have reported that most fiber-producing varieties of hemp require a frost-free growing season of five months or longer to produce seed and approximately four months for fiber production. Van der Werf et al. (1999) addressed the issue of frost risk, noting that hemp seedlings can survive a short frost of -8 to -10°C (+14 to +18°F), whereas mature plants can handle brief exposures to temperatures as low as -5 to -6°C (+22 to+23°F). Compared to several agricultural crops common to Minnesota, frost resistance of hemp is reported to be comparable. For instance, Robinson (1943) noted that hemp will survive fall frosts better than corn. In comparison to sugar beet, fiber hemp is reported to be at less risk to frost during plant emergence, but more at risk for a longer period.

Aside from the issue of plant survival under frost, perhaps as important is the issue of fiber yield under different lengths of growing period. Van der Werf et al. (1999) pointed out that the dates of planting and harvest have large effects on potential stem yields of hemp. They noted, for instance, that a site producing a yield of dry stem matter of 17.1 mt/ha during a period from planting to harvest of April 15 to September 15 would yield 9 percent less if the crop were planted April 30, and 20 percent less if planting did not take place until May 15. Similar reductions occur if the harvest date is moved to an earlier date than mid-September. Lengthening of the time span between sowing and harvest has the potential to substantially increase dry matter yields, but as Van der Werf et al. point out, the possibility of increased yields must be weighed against the increased risk of frost damage.

With respect to rainfall and soil moisture requirements, hemp appears to require moist growing conditions early in the growing season, but well-drained soils for maximum production. Wright (1941) and Robinson (1943) report that hemp is very sensitive to drought conditions, especially early in the growing season until plants become well established. Reports regarding late season response to drought are varied. Some proponents of industrial hemp production report, for example, that hemp is a very drought tolerant crop. In contrast, virtually all early reports of hemp performance (Wright, 1941; Robinson, 1943), as well as more recent writings (Rosenthal 1993), indicate stunting of plant growth and substantial yield reduction under drought conditions.

Needs for Irrigation and Fertilization

Given the apparent susceptibility of hemp to damage from drought conditions, consideration of the potential for short-term irrigation may be warranted. In fact, an Oregon State University study (Ehrensing 1998) concluded that in the Pacific Northwest Region, " . . .hemp will almost certainly require supplemental irrigation . . ." In the absence of Minnesota specific agronomic research, the extent to which irrigation would be necessary locally is not known.

The literature regarding fertilization requirements for hemp consistently indicates a need for phosphate and potassium application at the time of planting, generally at a rate consistent with wheat production (Ranalli 1999; Rosenthal 1993; Van der Werf 1994).

Jordan et al. (1946) reported results of fertilizer trials on hemp, noting stalk yield increases on the order of 26 to 100 percent, and bark fiber increases of 20 to 110 percent when applying 500 to 2,000 pounds of fertilizer (0-10-20, 0-20-20, 0-10-30) per acre. Although fertilization increased fiber yield, fiber strength was found to be reduced 8 to 13 percent. One of the most extensive discussions of fertilizer requirements for industrial hemp can be found in Walker (1990). Citing a number of contemporary authors (Kirby 1963; Berger 1969; Dempsey 1975), Walker points out that, despite claims to the contrary, fertilization of hemp is required, in part because hemp production removes large quantities of minerals from the soil.

To put requirements for fertilization into perspective, it is worth noting that all of the highest dry stalk yields reported by advocates of domestic hemp production are yields obtained with the benefit of fertilization.

Requirements for Pesticides and Herbicides

Van der Werf et al. (1996) acknowledge claims made by hemp advocates to the effect that hemp requires little or no pesticide and few to no herbicides, but then point out that hemp is not disease free. These authors specifically refer to the fungus *Botrytis cinerea*, commonly known as gray mold, and point out that this fungus can cause severe damage to hemp growing in the Netherlands in wet years. Pate (1999) explains that a number of fungal pathogens attack both hemp seeds and plants. MacPartland (1999) reports that at least 88 species of fungi are responsible for disease problems in hemp, but that only a few cause significant crop losses. MacPartland also identifies gray mold as having the potential to cause serious damage. He notes that high humidity at temperatures between 68 and 75°F can lead to epidemic levels of gray mold that can completely destroy a crop of hemp within one week. Root-infecting nematodes are also identified as a serious problem, and specifically in Canadian hemp. De Meijer et al. (1995) reported results of field trials in the Netherlands for the years 1987 through 1989. Attempts to grow hemp without applying herbicides resulted in crop yields that were 25 to 40 percent lower than yields obtained in subsequent years in which herbicides were applied.

MacPartland summarized disease and insect problems in hemp as follows: "Many current authors claim hemp is problem-free (Herer 1991; Conrad 1994; Rosenthal 1993). None of these authors has ever cultivated a fiber crop. In reality, hemp is not pest-free, it is pest tolerant; many problems arise in *Cannabis*, but these problems rarely cause catastrophic damage. However, diseases and pests cause small losses that may accumulate over time to significant numbers. Agrios (1988) estimates that 13 percent of fiber crops are lost to insects, 11 percent are lost to diseases, and 7 percent are lost to weeds and other organisms. In addition to these losses in the field, Pimental et al. (1991) adds another 9 percent in post-harvest losses. Add these numbers up and you reach 40 percent." MacPartland concludes with the observation that "As long as *Cannabis* continues to be grown in artificial monoculture, we will continue to need pesticides." It is clear that MacPartland uses the term "pesticide" to refer to both fungicides and insecticides.

Most reports suggest little need for herbicides with hemp production. However, this point needs a bit of clarification since some claims suggest that no attention to weeds is necessary. Wright (1942) notes that hemp is one of the best plants for smothering weeds, but cautions that the soil must be properly prepared prior to planting. He describes ideal planting preparation this way: "Early in the spring the soil should be worked up thoroughly and kept worked up to the very time hemp is seeded. He later reported (1943) that a corrugated roller used just before and just after seeding is a good way to get the seedbed in shape.

The net effect of pest-related problems and intensive demands placed on soil by hemp growth is that repeated cropping of hemp on the same site is not recommended. Robinson (1943) was one of the first to recommend that hemp should not be grown continuously on the same soil. He recommended that hemp be rotated in alternative years with corn. Rosenthal (1993) modified Robinson's recommendation, noting that hemp does best in rotation with other crops, including corn, wheat, oats, peas, alfalfa, and potatoes. He went on to say that hemp should be grown on a given field only one every two to three years. He also advised that "hemp cannot be grown on the same field continuously without fertilizer."

Harvesting

Traditionally, the harvesting of hemp involves cutting of stalks in the fall, often following chemical defoliation to promote pre-harvest drying. The hemp is laid down in a swath by mechanical harvesters and allowed, thereafter, to lay on the ground for 10 to 30 days (Robinson 1943). An on-the-ground storage period is important to the hemp fiber production process in that it promotes bacterial and fungal breakdown of pectins that bind fibers within the stems. Further drying of stalks also occurs during this period. The process is known as "retting" or "dew retting." Today, dew retting is a part of the harvest process in most hemp-producing regions.

In many ways the retting process is the Achilles heel of hemp fiber production, and is reported to have contributed to decline in hemp production and use in the 1940s. The idea of retting is to achieve partial rotting of the outer layers of the stalks, but to stop degradation at the proper time. Halting degradation requires that stems be dried to a green basis moisture content of 16 percent or less prior to baling. The process is, of course, highly weather dependent, and typically requires periodic turning of felled stalks in order to expose the entire stalk surface to microbial degradation (Walker 1990). Hessler (1945) reported on the effects of the retting period and retting conditions on fiber strength. He indicated that fiber strength is inversely related to the retting period and cautioned against excessive retting periods. He also indicated that retting over the winter season results in weak fiber.

An alternative to dew retting is water retting, a process which involves the laying of stalks in water (in tanks, ponds, or streams) for about 6 to 18 days. Ergle et al. (1945) indicated that water retting resulted in superior strength and quality of fiber as compared to that which is dew retted. Retting is reported to be significantly enhanced if the water is warm and/or laden with bacteria (Ranalli 1999).

Ranalli (1999) has commented at length on the retting process, noting that "Fiber extraction from fiber crops by traditional retting methods is highly polluting or carries high risks of crop failure and yields of varying fiber quality over the years. Nonpolluting processing techniques, which guarantee constant fiber qualities for industrial buyers are urgently needed." Ranalli further stated that "Water retting is unlikely to be viable on a modern farm as it is awkward, time-consuming, and produces an effluent that can be a source of pollution."

Walker (1990) also examined water retting in the context of textile fiber production, reporting findings that finer and better quality fibers are obtained from water or tank retting than from dew retting. He also noted that water retting is highly labor intensive as well as expensive, and described it as unsuitable for commercial scale adoption. A similar conclusion was reached by Ranalli regarding retting processes used with textile fiber production. He commented that "What is certain is that unless the problem of retting is overcome, it will not be possible to produce textiles from hemp economically in countries with temperate climates."

French investigators have tackled the retting problem and in recent years have developed an enzymatic retting process. The sequence begins with separation of hemp stalks into bark and core fractions using equipment long used for processing of flax. The outer bark fraction is then cut into one-foot-long segments prior to exposure to enzymes selected for their ability to break down pectins (Rosenthal 1994b).

Storage of Harvested Stalks

Perhaps because hemp is used commercially only on a small scale around the world there is little published information focused on the issue of stalk storage prior to processing. One of those who has commented on this issue (De Groot et al. 1999) notes that to totally supply the fiber needs of a modern kraft pulp mill would require the harvesting of about 250,000 acres each year. Pointing out that harvesting occurs over a brief span of time each fall, these authors conclude with the observation that "Consequently, large logistic problems must be solved (storage, transportation, guaranteed annual supply) and large investments must be made (apart from the start-up costs), before such a mill can be built for kraft pulp production using fiber hemp or any other fiber crop."

Given the general lack of information about storage of hemp stalks, it is informative to examine the literature regarding long-term storage of agricultural crop residues or annual crops in general. Because agricultural materials are produced over a one to three month period each year, storage of this material for use in an ongoing production operation is a concern. Intuitively, cereal straws and similar biomass materials should require covered storage to protect it from wetting from snow and rain. However, the volumes potentially requiring storage are quite large for processing facilities of sufficient capacity to achieve economies of scale.

A number of studies of the commercial potential for agri-based fiber have concluded that covered storage is necessary. For example, a study of opportunities in grass straw utilization, as reported by Ehrensing (1998), included the conclusion that "providing storage facilities and holding stocks of raw materials to ensure uninterrupted supply to a mill will involve considerable investment. Estimated storage costs for grass seed straw in western Oregon range from $13.22 to $14.23 per short ton, assuming a six-month storage period. This figure includes costs of construction, interest, repairs, insurance, and straw losses." A similar estimate of storage costs ($14-15/short ton), which included the cost of working capital tied up in stored fiber, resulted from a recent study of papermaking from kenaf (Bowyer 1999).

However, as noted by Wagner (1999), there are a number of options for storing straw, many of which do not involve construction of a building, or even covered storage. Options include: 1) storage of all annual supply at the mill, 2) storage of a portion of the annual supply at regional storage facilities owned by a mill, with the rest stored at the mill, 3) storage of a small portion of straw at the mill as a buffer supply with the rest stored at nearby farms, and 3) all annual supply is stored at the mill. Further options include storage within buildings, tarp covered storage in farm fields or elsewhere, and uncovered storage at the farm, regional storage site, or mill.

Several sources have reported that to prevent degradation of straw bales, the bale moisture must be maintained below 8 to 12 percent wet basis moisture content (McCloskey 1996, Wilcke et al. 1998), as bales with higher moisture are reportedly susceptible to rot and spontaneous combustion. However, experience at an industrial firm that is currently using agricultural residues as a raw material for making medium density fiberboard suggests that maintenance of bale moisture content at 18 percent green basis or less is sufficient. All those reporting on this issue agree that storing hay at moisture contents above 20 percent will result in development of mold and internal heating, greater dry matter loss (than if stored at a low moisture content), and discoloration. Not surprisingly then, high spoilage is reported in Minnesota and Wisconsin for baled hay stored in ground contact. Losses of 22-23 percent were experienced by mid-June for fall harvested stalks that were uncovered and in ground contact, compared to a 1 to 8 percent loss of bottom bales stored on gravel or inside a barn (Wilcke et al. 1998).

By covering outside-stored bales with a tarp, losses can be reduced by one-half or more (Wagner 1999). Estimates of the seasonal costs of tarped storage range from $2-6/short ton. Estimates of the costs of tarp covered storage are based simply on the cost of large tarps that last from 1 to 4 years. Costs of handling, land rent, or other factors are not included in these estimates. It is clear, however, that the costs associated with tarped storage are considerably less than the cost of storage within a dedicated structure (Wagner 1999).

All of these studies notwithstanding, the most common practice for currently operating agricultural residue-based industries involves outdoor storage of uncovered bales, a practice that is variously reported as satisfactory and unsatisfactory. Apparently satisfactory practices include those of another medium density fiberboard manufacturer in North Dakota which, for example, stores straw on bare clay soil, packing the bales into piles of 50 bales long by 6 bales wide, by 6 bales high. These bales are then left uncovered. Only the outer 6-12 inches reportedly show degradation from weather, even at the end of the storage season (Stern 1998). A similar plant in eastern Montana employs uncovered storage as well.

In contrast to the apparently satisfactory uncovered straw-storage practices referenced above, significant problems are also reported. Such problems include substantial degradation and loss of straw late in the storage period and development of wet pockets in bales that inhibit efficient processing of baled straw.

In short, it appears on the one hand that the fiber storage issue is not necessarily as significant as it is sometimes perceived to be. On the other hand, however, this is an area that has the potential to significantly impact mill operations and profitability, and thus one that must be carefully addressed in planning.

Industrial Hemp as a Papermaking Material

Technical Aspects of Hemp Paper Production

As previously noted, hemp stalks are composed of an outer layer of long bast fibers (also called bark fibers) that make up about 35 percent of stalk volume, and an inner core (also referred to as hemp hurds) composed of much shorter fibers. The viability of hemp as a papermaking material depends, in part, on the technical feasibility of using both the bast and core fibers, rather than simply one or the other.

De Groot et al. (1999) point out that the long bast fibers of hemp have been used for making paper ever since the invention of paper by the Chinese in 105 AD. They report, however, that little if any core fiber was used historically for papermaking, and that very little is used for this purpose even now. Supporting the observation about current use is a recent report (Dutton 1997) which indicated that France (a leader in commercial development of industrial hemp) had been exploring innovative uses for hemp hurds (hemp core), including such applications as insulation and cement additives. Van der Werf (Rosenthal 1994b) also recently reported on use of hemp in France, noting that a subsidiary of Kimberly Clark is manufacturing paper from both flax and hemp bark fibers. Core fibers, however, are reportedly being sold for alternative uses; use of core fibers for pet litter and for particleboard manufacture were identified. The fact that hemp core is being sold into relatively low value markets suggests lack of success in attaining commercial adoption of higher value applications such as papermaking fiber.

Johnson (1999) addressed the use of hemp as papermaking fiber, observing that " . . . current research has yet to yield a full-scale commercial pulping technology for anything beyond the high-cost, traditional specialty bast fiber pulps for high strength, thin applications such as bank notes, cigarette paper, and bibles. Though viable markets exist for specialty papers, demand is not increasing at a rate comparable to other wood-based, commodity grade paper (writing paper, fax and copier paper, newsprint, product packaging, etc.). To alleviate pressure on the timber industry or replace wood altogether in commodity-grade papers, high-yield and high-quality pulping technologies specifically for *cannabis* fiber - which would utilize all of the fiber (bast and core) in the stalk - would have to be developed."

De Groot et al. (1999) have extensively evaluated bast fiber as a papermaking raw material using a variety of pulping methods. Their findings indicate that industrial hemp bast fiber has a wide range of potential applications in modern papermaking. Specifically they reported that the properties of unbleached alkaline mechanical pulps made of hemp bast fiber were sufficient to warrant consideration for use in production of linerboard. Comparing unbleached hemp bast fiber mechanical pulp with softwood thermo-mechanical pulp, they found the hemp pulp to have higher tear strength, but higher density. They also found that properties of bleached alkaline mechanical pulp were such that this material could be used to replace bleached chemi-thermomechanical softwood pulp in printing and writing grade papers. Similar potential was found for replacement of northern softwood bleached kraft pulp with hemp bast alkaline peroxide mechanical pulp; in this case, tensile strength of the hemp pulp was found to be lower than that of the softwood pulp, while density and tear of the hemp pulp were found to be significantly better. Based on such studies, it is rather evident that from a technical point of view the outer bark (or bast) fibers of hemp are very acceptable raw materials for use in contemporary papermaking.

Recent pulping studies of hemp bast fiber clearly indicate why hemp bast fiber pulp has a long history of applicability in several specialty markets. It is less clear why hemp core fiber has failed to achieve market acceptance, particularly in view of apparently positive research findings over a period spanning the period 1916 to the present. De Groot (1999) makes reference to studies in the United States (Dewey and Merrill 1916), in Italy (Bosia 1975), in the Netherlands, and in Germany, noting that all of these studies have indicated that hemp woody core is a promising papermaking raw material (de Groot et al. 1999).

Zomers et al. (1995) evaluated pulping of both the bast and core fractions of industrial hemp using autoclaved organosolv pulping. These researchers found high yield, long fiber length, and high tear strength in bast fiber pulp, and concluded that such material would be ideal for use in paper products requiring high tear strength, stiffness, or bulk. The concluding observation in this case was that "this pulp may be interesting for use in printing, writing, or copying papers." Abdul-Karim et al. (1994) examined process variables associated with production of hemp dissolving pulp. They concluded that whole stalk hemp was a suitable raw material for production of cellulose derivatives. De Groot et al. (1999) also extensively investigated hemp woody-core pulps. They found that brightness, burst, and crystallinity values are comparable with hardwood pulp and that the effects of beating on wood and hemp pulps is similar. They concluded that hemp woody-core pulp is comparable to hardwood pulps used in printing paper grades and that hemp core could be optimally produced so as to be a suitable component in pulp mixes for printing papers. Thus, recent technical evaluations of pulp made from the core of industrial hemp stalks have yielded very encouraging results. Pulp strengths comparable to commonly used hardwood and softwood pulps have also been obtained. Taken together, these studies suggest considerable potential for use of hemp core as a papermaking raw material.

While the previously cited research appears to indicate technical suitability of industrial hemp fiber for use in paper manufacture, all of these studies have examined pulp produced separately from either bark or core of hemp stalks. A relevant question, that has significant implications for pulping economics, is whether it is technically possible to pulp whole hemp stalks while obtaining acceptable paper properties. Zomers et al. addressed this question, finding that pulp made using the organosolv process from whole stems of industrial hemp yielded test paper strengths intermediate between commercial chemical hardwood and softwood pulps. However, noting severe reduction of the tear strength contribution of bast fibers, and in recognition of chemical and morphological differences between core and bast fiber, researchers recommended separate pulping of core and bast fiber. Results suggest that a pulp consisting of a blend of core and bast fiber, whether pulped separately or together in one operation, would yield a pulp with acceptable properties for many applications.

Given substantial differences in the hemp bark and core, differences in manufacturing processes needed to achieve optimum processing of the two fractions, and potential high-value specialty markets for the bast fiber fraction, it appears likely that bark/core separation would precede any commercial pulping of hemp. Thus, the costs of separation should be considered in any economic evaluation of hemp pulping.

<u>Economic Considerations in Pulping of Industrial Hemp</u>

An extensive discussion of the economics of U.S. hemp production can be found in the January 2000 USDA report *Industrial Hemp in the United States: Status and Market Potential.* This discussion focuses on probable returns to hemp producers visa-vis other potential crops, and is based on earlier assessments of hemp agriculture involving the states Oregon (Ehrensing 1998), Kentucky (Vantreese 1997), and North Dakota (Kraenzel et al. 1998). This discussion is not repeated here; instead, the reader is directed to pages 17 through 22 of the USDA report which is provided in full as Attachment A of this report.

The 1998 North Dakota evaluation of the feasibility of agricultural production of dual purpose hemp crops (hemp fiber and hemp seed) assumed values of hemp stalks of $40.44, $45.96, and $51.47 per short ton, and of hemp seed of $5.51, $6.16, and $6.80 pr bushel. The dollar values were converted from Canadian prices. The middle and highest estimates of value were shown to provide higher net returns to farmers than common crops such as spring wheat, feeder corn, malting barley, and confectionery sunflowers. It is interesting to note that the largest component of projected income comes not from the fiber of the stalk, but from the seed. As discussed earlier (see Site Requirements section), production of seed requires a growing season that is at least a full month longer than is needed for production of stalks alone (five months plus for seed vs. four months for fiber only). Thus, the much higher income projected from sales of both stalks and seed is associated with a significantly higher risk of early or late season crop damage.

Projected costs of hemp pulp were compared to costs of producing hardwood and softwood pulp. Economic comparisons were based on work of the Paper Task Force (1996) which examined costs of producing various kinds of pulp from wood and from kenaf. In assessing likely costs of producing hemp pulp, hemp stalk values equivalent to those derived in the North Dakota hemp evaluation report (Kraenzel et al. 1998) - \$45.96 and \$51.47 per short ton - were used. The highest of these two prices, (\$51.47/short ton or \$56.62/ metric ton), is almost exactly equal to the estimated price at which southern farmers could profitably deliver kenaf stalks to local paper mills (Bowyer 1999). Pulp costs were also examined using hemp stalk prices 20 percent above the highest value, or \$61.76 per short ton.

Scenarios Evaluated and Basic Assumptions

Economic comparisons were conducted for three different scenarios:

1) Whole stalk TMP and CTMP pulping of industrial hemp was compared with TMP pulping of aspen and of white spruce.

2) Hemp bark (or bast) fiber chemical pulping and bleaching, and hemp core fiber chemical pulping and bleaching, were compared with chemical pulping and bleaching of aspen.

3) Whole stalk chemical pulping and bleaching of hemp was compared with chemical pulping and bleaching of white spruce.

Only differential costs were considered in the economic comparisons (i.e. costs that would be the same for the various alternatives being examined were not considered).

Assumptions that applied to all scenarios included the following:

- Hemp would be harvested once annually, with delivery of field-dried stalks to the mill (or to stalk storage areas) occurring over a four to six week period each year.
- A mill using hemp exclusively would need covered storage facilities sufficient to handle at least ten months of fiber requirements.
- Hemp fiber in storage would range from a one-month supply to a ten-month supply. On average, working capital equivalent to the delivered value to a five-month supply of fiber would be needed for a hemp mill.

- Wood in storage would range from a one-month supply to a three-month supply. On average, the working capital equivalent to the delivered value of a one and one-half month supply of fiber would be needed.
- Fiber losses in storage are the same for hemp and for wood. Alternatively, it was assumed that fiber losses for hemp in storage would be double that for wood.

Scenario One - Mechanical Pulping

Other than the costs associated with fiber storage, the primary issue in mechanical pulping is the cost of energy. The cost of energy assumed in this analysis is the industrial cost for electricity ($0.0456/kwh) as reported for Minnesota for the year 1999 (US Energy Information Administration 2001). When CTMP is employed, the costs of pulping chemicals are also significant. Projected costs for each system are presented in Table 8.

This analysis suggests that hemp TMP or hemp CTMP can be produced at 67-78 percent of the cost of producing hardwood TMP. This result is, of course, dependent upon the assumptions used in the study. Results are most dependent upon energy costs, with lower costs of energy more favorable to wood-derived pulps. However, even when using the lowest reported electrical energy cost nationwide ($0.027/kwh), the projected costs of producing hemp mechanical pulps are still at only 70-81 percent of the costs of producing mechanical pulps from wood. Results are also obviously sensitive to raw materials costs.

It is worthwhile considering that the figures presented in Table 8 do not include any costs that might be associated with covered storage of hemp fiber. If it is assumed that fiber must be stored under a roof once it is field dried, and if it is further assumed that a structure large enough to accommodate ten months of fiber needs would be needed, then capitalization costs associated with the drying facility could add as much as $14-15/odmt of pulp. Moreover, it is assumed in this analysis that fiber loss in storage is the same for both hemp and wood; if this is not the case, then a significant difference in fiber loss would obviously affect the relative cost of fiber. If, for example, hemp losses in storage were assumed to be as high as 20 percent, production costs for hemp mechanical pulps would rise to about 72-84 percent of costs associated with production of mechanical pulp from aspen. Adding in capitalization costs for a storage structure increases the estimated cost of producing hemp mechanical pulps to 78 to 90 percent of that of aspen pulp - still a substantial difference in favor of hemp.

Table 8

A Comparison of Differential Costs Associated With Various Types of Mechanical Pulp

(costs are expressed as dollars per o.d.m.t. of pulp)

Item	Hemp stalk value $45.96 per dry short ton		Hemp stalk value $51.47 per dry short ton		Hemp stalk value $61.76 per dry short ton		
	Whole Stalk Hemp TMP[a]	Whole Stalk Hemp CTMP[a]	Whole Stalk TMP[a]	Whole Stalk Hemp TMP[a]	Whole Stalk Hemp TMP[a]	Whole Stalk Hemp CTMP[a]	Aspen TMP
Delivered cost of fiber[b]	$ 55.56	$ 58.79	$ 62.22	$ 65.83	$ 74.65	$ 79.00	$ 82.22
Cost of working capital for stored fiber[c]	2.34	2.45	2.59	2.74	3.11	3.29	1.02
Process energy[d]	115.37	97.79	115.37	97.79	115.37	97.79	165.03
Process chemicals		7.89		7.89		7.89	
Total Costs	$173.27	$166.92	$180.18	$174.25	$193.13	$187.97	$248.27

[a] pulping yields for hemp were assumed to be the same as for kenaf - 91% and 86% for hemp TMP and hemp CTMP, respectively, and 95% for wood TMP as reported by the Paper Task Force (1996).

[b] Based on delivered costs as indicated for hemp and $70/cord (delivered) for aspen.

[c] Based on mill production of 750 tons per day, an average fiber inventory equivalent to 5 months production for hemp and 1 1/2 months production for wood, and a cost of capital of 10%.

[d] Based on power requirement of 1888, 1611, and 2472 kwh/ADT for hemp TMP, hemp CTMP, and aspen TMP, respectively (Paper Task Force, Table 9); power required assumed to be the same for aspen as for SYP. Power costs of $0.0456/kwh assumed (US Energy Information Administration 2001).

Scenario Two - Hemp Bark (or Bast) Chemical Pulping and Bleaching, vs Hemp Core vs. Spruce vs. Aspen Chemical Pulping and Bleaching

Other than costs associated with fiber storage, the primary economic issues in chemical pulping and bleaching are total energy costs and non-energy costs associated with bleaching.

This analysis was based on figures developed by the Paper Task Force (1996). Costs of fiber, energy, and chemicals assumed in this analysis are given in the column headings and footnotes to Table 9. It was further assumed in this analysis that the bast and core portions of hemp would be separated prior to pulping, and pulped separately. Costs of stalk separation and chipping of round pulpwood logs are shown in Table 10.

Based on the assumptions used in this study, bleached chemical pulps made from aspen or spruce are significantly less costly to produce than such pulps made from hemp; differences in production costs are projected to range from 24-34 percent. Costs of chipping in the case of wood, and fiber separation, in the case of hemp, need to be added to the costs shown in Table 9; as these costs are estimated to be roughly equal, they have been omitted from all calculations.

Adding fiber storage costs to the cost figures shown in Table 9 slightly widens the differences in projected production costs (Table 10).

Table 9

Projected Operating Costs for Hemp and Wood-Based Chemical Pulp Mills in Minnesota

(costs are expressed as dollars per o.d.m.t. of pulp)

	Hemp stalk value $45.96 per dry short ton		Hemp stalk value $51.47 per dry short ton		Hemp stalk value $61.76 per dry short ton			
Item	Hemp Core[a]	Hemp Bast[a]	Hemp Core[a]	Hemp Bast[a]	Hemp Core[a]	Hemp Bast[a]	Aspen[a]	Spruce[a]
Fiber[b]	$189	$253	$212	$283	$254	$340	$206	$253
Energy/chemicals[c]	212	199	212	199	212	199	143	153
Labor[d]	118	118	118	118	118	118	48	52
Operating Costs	$519	$570	$542	$600	$584	$657	$397	$458

[a] Based on figures from Paper Task Force (1996), Table 12.

[b] Based on delivered costs of hemp as indicated, and $70/cord (delivered) for aspen roundwood, $85 spruce roundwood, and assuming yield after pulping and bleaching of 44% for both aspen and spruce (Paper Task Force), 38% for hemp core (Table 5), and 67% for hemp bast fiber (Table 5).

[c] Used same energy and chemical costs as in Paper Task Force report (1966), inflated to reflect current energy and chemical prices. Energy prices obtained from the U.S. Energy Information Administration (2001). Chemical prices increased by multiplying by composite Producer Price Index, 1995-1999 [1.0064].

[d] Labor costs used in the Paper Task Force report were adjusted by inflating values 3% per year for five years.

If delivered costs for hemp are assumed to be as high as $61.76/admt, then the cost differences as indicated above become even higher - as much as 40 percent. Similarly, higher assumed costs of energy and chemicals would also increase the costs of hemp pulps relative to pulps made from wood.

Table 10
Projected Operating Costs, Including Fiber Inventory and Storage Costs for Hemp and Wood-based Chemical Pulp Mills in Minnesota

	(costs are expressed as dollars per o.d.m.t. of pulp)			
Item	Aspen	Spruce	Hemp core	Hemp bast
Fiber, energy, chemicals & labor[a]	$397	$458	$542	$600
Cost of working capital for stored fiber [bc]	2.00	2.41	7.51	5.50
Total Costs	$399	$460	$550	$600

[a] Based on delivered cost of hemp of $51.47 per dry short ton, and delivered costs of aspen and spruce pulpwood logs of $70 and $85/cord, respectively.
[b] Based on 300 ton/day hemp pulp mill and assuming hemp bast core separation and yield of 35% and 65% for bast and core, respectively. Also assumed 10% fiber loss of hemp in the separation process, and chemical pulping yield (bleached) of 67% for bast and 38% for core. Average fiber inventory equivalent to 5 months of production.
[c] Based on 1000 ton/day wood pulp mill with chemical pulping yield of 44%. Average fiber inventory equivalent to 1 1/2 months of production assumed.

As in the previous scenario, the figures presented in Tables 9 and 10 do not include any costs that might be associated with covered storage of hemp fiber. In this case, if it is assumed that fiber must be stored under a roof once it is field dried, and that a structure large enough to accommodate ten months of fiber needs would be needed, then capitalization costs associated with the drying facility could add as much as $22-31/odmt of pulp. Additionally, it was again assumed in this analysis that fiber loss in storage is the same for both hemp and wood, an assumption that if wrong would obviously affect the relative cost of fiber. For example, if it is assumed that hemp degradation in storage is double that of wood (10 percent vs. 5 percent) the result is an increase of about $10 to$14 per ton of hemp pulp. Larger differences in storage loss would result in proportional changes in relative costs of pulp made from wood and hemp.

Although the magnitude of the cost differences shown in Tables 9 and 10 are substantial, the picture looks quite different if it is assumed that self-generated energy could be sold to the regional energy grid, and that its use would therefore appropriately represent an expenditure equivalent to the opportunity costs. The effect of such an assumption is to make the apparent production costs of wood-derived chemical pulps about equal to those of hemp pulps (see Table 12).

Scenario Three - Whole Stalk Chemical Pulping of Hemp vs. Spruce vs. Aspen

Projected costs of chemically pulping and bleaching whole stalk hemp were derived from the calculated costs of producing hemp bark (or bast) fiber and hemp core fiber pulps. Averages of the earlier calculated costs, weighted by the percent of bark and core fiber within whole stalk hemp (35 and 65 percent, respectively), provided the production cost estimate (Table 11).

Table 11
Projected Operating Costs for Whole Stalk Hemp and Wood-based Bleached Chemical Pulp Mills in Minnesota[a]

	(costs are expressed as dollars per o.d.m.t. of pulp)		
Item	Aspen	Spruce	Whole Stalk Hemp
Fiber[b]	$206	$253	$134
Energy, chemicals[c]	$143	$153	$200
Labor[d]	$ 48	$ 52	$118
Costs of working capital for stored fiber	2.00	2.41	5.58
Operating Costs	$399	$460	$458

[a] Based on figures from Paper Task Force (1996), Table 12.
[b] Costs calculated using delivered costs for hemp of $51.47/air dry (10%mc) metric ton ($51.477/od short ton), for aspen pulpwood of $70/cord, and for spruce of $85/cord, and assuming yield after pulping and bleaching of 44% for both hardwood and softwood, 48% for whole stalk hemp.
[c] Used same energy and chemical costs as in Paper Task Force report (1996)), inflated to reflect current energy and chemical prices. Energy prices obtained from the U.S. Energy Information Administration (2001). Chemical prices increased by multiplying by composite Producer Price Index, 1995-1999 [1.0064].
[d] Labor costs used in the Paper Task Force report were adjusted by inflating values by 3% per year for five years.

Here, the estimated costs of wood and hemp derived pulps are very similar. As in the previous analysis, increases in the delivered cost of hemp or to changes in energy and/or chemicals costs widen the differences in the cost of wood and hemp pulps. Also as previously indicated, provision of covered storage for hemp stalks would add on the order of 5 percent to production costs ($25-26/ odmt).

The one assumption that makes chemically pulped and bleached whole stalk hemp fiber economically attractive is the assumption that self-generated energy could be sold to the regional energy grid, and that its use would therefore appropriately represent an expenditure equivalent to the opportunity costs. As noted previously, the effect of such an assumption is to drive the apparent production costs of wood-derived pulps to levels about equal to those of hemp pulps (see Table 12).

Table 12
Projected Operating Costs, Including Operating Costs Associated with Self-Generated Energy for Whole Stalk Hemp and Softwood-based Chemical Pulp Mills in Minnesota

(costs are expressed as dollars per o.d.m.t. of pulp)

Item	Aspen	Spruce	Whole Stalk Hemp
Operating costs[a]	$399	$460	$458
Opportunity costs associated with self-generated energy[b]	160	160	10
Total Costs	$559	620	$468

[a] From Table 11.
[b] Based on an energy buyback rate of $0.22/kwh.

Environmental Aspects of Hemp vs. Wood Production

A number of proponents of commercial hemp production suggest a number of environmental advantages of hemp fiber, rather than wood fiber production. Clues as to likely environmental impacts of commercial hemp production in Minnesota can be obtained by examining conclusions regarding other annual crops. Kaldor (1992), for example, addressed environmental considerations related to kenaf production, saying simply that " . . . the purchasing public is becoming increasingly conscious and environmentally aware of the need to preserve forests." Wood and Angus (1976), writing about the situation in Australia, noted that if periodic clearcutting of forests is curtailed, then this would favor kenaf as a substitute for eucalypt pulpwood. However, they also noted that cultivation of kenaf may itself cause environmental problems, citing the need for energy-intensive nitrogen and phosphate fertilizers, irrigation water, and higher inputs of fossil fuel energy in farming.

A significant environmental disadvantage of any annual fiber crop as compared to tree plantations is the frequency of activity on the landscape (Bowyer 1995). Consider, for example, a hybrid poplar plantation that is grown to an age of 20 years before harvest. Site intervention would occur three to six times over the 20-year rotation (once or twice to prepare the site, once to plant, zero to two times to suppress competition, and once to harvest). Compare this with kenaf production as outlined by Scott and Taylor (1990): annual activities including chisel, disc, disc/herbicides/disc (2X), application of pre-plant fertilizer, bedding, seeding and planting, application of side-dressing, cultivation, and harvesting. Based on findings in this study, the hemp production sequence would be similar, involving four to six passes across a site prior to and during seeding, one pass to harvest, and potentially several passes associated with retting and periodic turning of stalks and stalk pick-up. Assuming this sequence of production steps, direct site impacts would occur 140 to 200 over a 20-year time span. This reality not only dramatically increases fuel requirements, but also greatly increases the risk of such things as soil erosion and impacts on water quality. It is, therefore, difficult to argue that hemp production is environmentally preferable to production of wood fiber, especially if about the same land area is required for production of hemp as for wood fiber. Environmental advantages appear questionable even if annual hemp yields are assumed to be as much as 70 percent greater than wood yields from poplar plantations.

Whereas the use of specific fiber crops such as hemp is questionable from a social perspective, the same cannot be said for agricultural residues. These are by-products of food production that in many areas of the world currently represent a disposal problem. The use of these materials is both socially and environmentally attractive, as long as volumes removed from the land do not compromise soil conservation.

Summary

Even though paper recycling is steadily rising, expanding paper demand is placing increasing demands on the forests of the U.S. and the world. One strategy being widely pursued is to establish large areas of highly productive forest plantations. Planting initiatives have been highly successful, with an increasing portion of U.S. and world fiber needs coming from plantations covering a relatively small land area. It is possible that future wood and fiber needs can be completely supplied by forest plantations, although a substantial investment will be required to ensure sufficient increases in plantation area and technology development aimed at increasing annual fiber yields on each acre. Moreover, should expansion of plantations in Minnesota not keep pace with developments in the U.S. South or elsewhere, Minnesota's paper industry is likely to face a declining market share.

Interest in alternative sources of fiber is growing as concerns rise about the state of the world's forests. One potential alternative is hemp (*Cannabis sativa* L.). Hemp has a number of properties that favor its use as a papermaking raw material. About one-third of the fiber of the hemp stalk, that from the outer layers or "bark," is quite long, a desirable quality for developing high-strength paper. Also, the proportion of lignin throughout the stalk is lower than in wood, a property that favors high pulp yields. Hemp has a long history in the U.S., grows rapidly, and is suited to the climate of southern Minnesota. Significant increases in growth rates are thought possible through genetic improvement. Also, fiber from hemp bark has also been found by a number of researchers to be an acceptable raw material for use in contemporary papermaking, and it appears that hemp paper could be manufactured at a competitive price to paper made of wood pulp.

Despite promising attributes of industrial hemp, several factors suggest that development of an industrial hemp-based paper industry in Minnesota should not be pursued without very careful consideration.

Factors dictating caution include:

- Hemp growth rates are markedly lower than kenaf, another agricultural fiber currently being promoted as a papermaking raw material. The relatively slow growth rates of hemp could place Minnesota farmers at a considerable disadvantage to those several hundred miles to the south who could raise fiber crops of kenaf.

- Hemp crops are highly sensitive to early and late season frosts, a reality that could prevent reliable production of seed that is needed to make hemp production economically attractive to farmers.

- Although industrial hemp is not likely to be an economically viable source of marijuana, separation of industrial hemp from hemp grown as a narcotic is extremely difficult.

- Separation of bark and core portions of hemp stalks are thought by many to be necessary for optimum processing of hemp. However, retting, an integral part of the bark/core separation process, is reported to require substantial improvement prior to large-scale use of industrial hemp as a fiber source.

- Long-term storage of large volumes of hemp would be needed following harvest were hemp to become a principal papermaking fiber.

- In comparison to industrial fiber productivity in tree plantations, production of hemp fiber would likely result in significantly greater environmental impacts, even if it is assumed that annual hemp yields per acre would be as much as 70 percent greater than yields from poplar plantations.

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Appendix

Industrial Hemp in the United States: Status and Market Potential

Abstract

Industrial hemp has been the focus of official interest in several States. However, hemp and marijuana are different varieties of *Cannabis sativa*, which is classified as a controlled substance in the United States. With Canada now allowing hemp production, questions have been raised about the demand for hemp products. U.S. markets for hemp fiber (specialty textiles, paper, and composites) and seed (in food or crushed for oil) are, and will likely remain, small, thin markets. Uncertainty about longrun demand for hemp products and the potential for oversupply discounts the prospects for hemp as an economically viable alternative crop for American farmers.

Keywords: industrial hemp, markets, bast fiber, hurds, seed, oil.

Washington, DC 20036-5831 January 2000

Contents

Executive Summary

Industrial hemp and marijuana are different varieties of the same species, *Cannabis sativa* L. Marijuana typically contains 3 to 15 percent of the psychoactive ingredient delta-9-tetrahydrocannabinol (THC) on a dry-weight basis, while industrial hemp contains less than 1 percent. However, the two varieties are indistinguishable by appearance. In the United States, *Cannabis sativa* is classified as a Schedule I controlled substance, regardless of its narcotic content, under the Controlled Substances Act as amended. Since 1990, varieties containing less than 0.3 percent THC have been legalized in Great Britain, Germany, Austria, and Switzerland. Canada and Australia legalized hemp production in 1998. In other countries, such as China, Russia, and Hungary, hemp production was never outlawed.

With Canada now allowing production of industrial hemp, questions have been raised about the potential commercial market demand for industrial hemp products in the United States. Hemp cultivation has been the focus of official interest in several States. The Governor of Kentucky established a Hemp and Related Fiber Crops Task Force in 1994. Legislation passed in Vermont, Hawaii, and North Dakota in 1996 and 1997 authorized agronomic and economic feasibility studies. In 1999, nine States (Arkansas, California, Hawaii, Illinois, Minnesota, Montana, New Mexico, North Dakota, and Virginia) passed legislation concerning the research, study, or production of industrial hemp as a crop. The first test plots of industrial hemp in the United States were planted in Hawaii in December 1999.

Previous experience in the United States and other countries indicates that industrial hemp grows well in areas where corn produces high yields. Plants require plentiful moisture throughout the growing season and need substantial amounts of available nutrients to produce high yields. Hemp can be grown as a fiber, seed, or dual-purpose crop. It is a bast fiber plant similar to flax, kenaf, and jute. The interior of the stalk contains short woody fibers called hurds, while the outer portion contains the long bast fibers. Hemp seeds are smooth and about one-eighth to one-fourth of an inch long.

No data are available on imports of hemp seed and oil into the United States, but data do exist on hemp fiber, yarn, and fabrics. Imports of raw hemp fiber have increased dramatically in the last few years, rising from less than 500 pounds in 1994 to over 1.5 million pounds for the first 9 months of 1999. Yarn imports also have risen substantially, peaking at slightly less than 625,000 pounds in 1997. The switch from yarn to raw fiber in the last 2 years probably reflects the development of U.S. spinning capacity. At least two companies are now spinning hemp yarn from imported fibers. Imports of hemp fabric have more than doubled from over 222,000 pounds in 1995 to about 523,000 pounds in 1998.

Current markets for bast fibers like industrial hemp include specialty textiles, paper, and composites. Hemp hurds are used in various applications such as animal bedding, composites, and low-quality papers. As joint products, finding viable markets for both hemp bast fiber and hurds may increase the chances of a successful business venture. Hemp industry sources and some academic studies cite many potential uses for hemp fiber and hurds. However, for these applications to develop or expand, hemp will have to compete with current raw materials and manufacturing practices. The U.S. market for hemp fibers is, and will likely remain, a small, thin market. Changes in price or quantity could be more disruptive and have a greater adverse impact on market participants than would be the case in a larger market.

Since there is no commercial production of industrial fiber hemp in the United States, the "size" of the market can only be gauged from hemp fiber and product imports. The near-term, low-end size of the U.S. market for hemp as a textile fiber might be defined by considering the domestic production and acreage required to replace imports of hemp fiber, yarn, and fabric in 1999. Assuming a potential U.S. yield of 1,550 pounds of fiber per acre and using linen yarn and fabric conversion factors, the estimated import quantity of hemp fiber, yarn, and fabric in 1999 could have been produced on less than 2,000 acres of land. Given the average size of farms in the United States (near 500 acres), just a few farms could have supplied the hemp fiber equivalent of 1999 import levels.

As a specialty bast fiber, hemp's closest competing textile fiber is linen. A longer term, high-end size of the potential U.S. market for hemp fiber could be defined as domestic production and acreage required to replace hemp and linen imports. The hemp fiber required to replace the equivalent level of hemp and linen fiber, yarn, and fabric imports in 1999 could have been produced on 250,000 acres—roughly 40 percent of 1999 tobacco acreage, 5 percent of U.S. oat acreage, or 0.4 percent of wheat acreage.

Despite the similarities between hemp and linen, there is no industry consensus as to how closely the markets for the two fibers are allied. But since hemp fiber imports were just 0.5 percent of linen imports during the first 9 months of 1999, the near-term market potential for hemp in the United States for domestic textile production is closer to the low end of the 2,000- to 250,000-acre production-equivalent range. Moreover, the absence of a thriving textile flax (linen) production sector in this country (despite no legal barriers) suggests that hemp, flax's close cousin in fiber uses and in production techniques, will be unable to sustain adequate profit margins for a large production sector to develop.

In 1998, imports of hemp seed into North America were estimated at 1,300 tons. Given yields in Germany of about 1,000 pounds per acre, it would take 2,600 acres to satisfy the demand for hemp seed. As with fiber imports, it would take only a few average-sized farms to meet this demand. Hemp seeds can be used directly as a food ingredient or crushed for oil and meal. Hemp seeds and flour are being used in nutrition bars, tortilla chips, pretzels, beer, salad dressings, cheese, and ice cream. The market potential for hemp seed as a food ingredient is unknown. However, it probably will remain a small market, like the markets for sesame and poppy seeds. Some consumers may be willing to pay a higher price for hemp-seed-containing products because of the novelty, but otherwise hemp seed will have to compete on taste and functionality with more common food ingredients.

Hemp oil is being used as an ingredient in body-care products, such as lotions, moisturizers, and shampoos, and sold in health food stores as a nutritional supplement. The market for hemp oil is limited by a number of factors. First, mechanical crushing produces a lower oil yield than crushing combined with solvent extraction. Nor does hemp oil undergo degumming and bleaching as do many other vegetable oils. Some consumers prefer an oil that has been processed without chemicals, but others may dislike hemp oil's color or taste. Second, the oil is high in unsaturated fatty acids, which can easily oxidize, so it is not used for frying and must be kept in dark-colored bottles and has a limited shelf life. Third, to be used as a salad oil, it will have to be tested by the U.S. Food and Drug Administration and found "generally recognized as safe." Last, as a drying oil, hemp would have to compete on functionality and price with current raw materials, such as linseed and tung oils, in established industrial markets.

Several States have published reports or authorized agronomic and economic feasibility studies of hemp production. The four reports summarized here have focused on different aspects of supply and/or demand. Their estimates of hemp costs and returns reflect these various focuses, as well as different assumed production practices and costs. However, the widest range of estimates exhibited among the reports is for stalk and seed yields and prices—not surprising given the uncertainty about hemp production and current and potential hemp markets. Overall, hemp production was profitable only at the higher end of estimated yields and prices. It seems questionable that U.S. producers could remain profitable at the low end of the estimated net returns, particularly given the thinness of current U.S. hemp markets.

The market for hemp products might easily be oversupplied, as in Canada where the 35,000 acres of hemp produced in 1999 was seemingly more than the market could handle. The *Minneapolis Star Tribune* quotes the general manager of Kenex Ltd., Canada's biggest hemp processor, as saying "It's given us one hell of a glut of grain and fiber. There's been a major overestimation of the market that's out there" (von Sternberg, 1999).

Industrial Hemp in the United States

Status and Market Potential

Introduction

Industrial hemp and marijuana are different varieties of the same species, *Cannabis sativa* L. In the United States, *Cannabis sativa* is classified as a Schedule I controlled substance, regardless of its narcotic content, under the Controlled Substances Act as amended. Regulatory authority is vested in the Office of the Attorney General and is carried out by the Drug Enforcement Administration (DEA). Since 1990, varieties containing very low levels of the psychoactive ingredient delta-9-tetrahydrocannabinol (THC) have been legalized in Great Britain, Germany, Austria, and Switzerland. Canada and Australia legalized hemp production in 1998. In other countries, such as China, Russia, and Hungary, hemp production was never outlawed.

With Canada now allowing production of industrial hemp, questions have been raised about the potential commercial market demand for industrial hemp products in the United States. Several companies import hemp fabrics and garments into the United States. Other firms import hemp fiber or sterile hemp seed for further processing and manufacturing into products, such as paper, nutrition bars, and beer.

Hemp cultivation has been the focus of official interest in several States. The Governor of Kentucky established a Hemp and Related Fiber Crops Task Force in 1994. Legislation passed in Vermont, Hawaii, and North Dakota in 1996 and 1997 authorized agronomic and economic feasibility studies. Published study results are available from Kentucky, Oregon, and North Dakota (McNulty, 1995; Thompson et al., 1998; Ehrensing, 1998; Kraenzel et al., 1998).

Since 1995, a total of 19 States (Arkansas, California, Colorado, Hawaii, Illinois, Iowa, Kansas, Maryland, Minnesota, Missouri, Montana, New Hampshire, New Mexico, North Dakota, Oregon, Tennessee, Vermont, Virginia, and Wisconsin) have introduced hemp legislation. In 1999, nine States (Arkansas, California, Hawaii, Illinois, Minnesota, Montana, New Mexico, North Dakota, and Virginia) passed legislation concerning the research, study, or production of industrial hemp as a crop (Nelson, 1999). The legislation in Minnesota and North Dakota permits the production of industrial hemp, provided farmers obtain licenses from DEA. Farmers are looking for alternative crops, particularly for tobacco, but also for rotation crops to break pest and disease cycles.

The first test plots of industrial hemp in the United States were planted in Hawaii in December 1999. To gain DEA approval of the project, scientists were required to enclose the plot inside a 12-foot-high fence with infrared surveillance (Welna, 1999; Associated Press, 2000). The project received $200,000 in funding from a hair-care company that uses hemp oil in its products (Hanks, July 1999).

This report examines the similarities and differences between industrial hemp and marijuana. It then reviews hemp's history as a crop; its plant characteristics and growing requirements; and harvesting, retting, and fiber separation. This is followed by a brief review of Canadian hemp production and a discussion of U.S. hemp fiber and fabric imports. The next two sections assess hemp fiber and seed markets. The following two sections discuss some of the issues involved in potential U.S. hemp production and processing and review estimated costs and returns for hemp production from four State-sponsored studies.

Identification: Industrial Hemp or Marijuana?

Marijuana and industrial hemp are different varieties of the same plant species, *Cannabis sativa* L. Marijuana typically contains 3 to 15 percent THC on a dry-weight basis, while industrial hemp contains less than 1 percent (Blade, 1998; Vantreese, 1998). Most developed countries that permit hemp cultivation require use of varieties with less than 0.3 percent THC. However, the two varieties are indistinguishable by appearance. DeMeijer et al. (1992), in a study of 97 Cannabis strains, concluded that short of chemical analysis of the THC content, there was no way to distinguish between marijuana and hemp varieties.

Industrial hemp can be grown as a fiber and/or seed crop. Grown for fiber, it is planted in dense stands to maximize stalk production. Grown for seed or for seed and fiber, plants are spaced farther apart to encourage branching and seed production. Marijuana varieties are grown for their leaves and flower buds, and therefore are grown under low-density conditions to maximize branching. Thus, planting density and other production characteristics do not offer a reliable way to distinguish varieties for law enforcement purposes.

Health Canada announced regulations on March 12, 1998, that control activities relating to the production, import, export, transport, and sale of industrial hemp (see Appendix I for the fact sheet from Health Canada). Production is highly regulated, with farmers required to obtain annual government permits. Farmers cannot have had a drug offense in the past 10 years and need to have a criminal background check done at their own expense. Federal agronomists and police will check fields and test plants to make sure that no narcotic plants are grown along with the industrial hemp.

The European Union (EU) issued rules governing hemp production in 1989, which include registration of the area to be planted in advance, the use of seed from certified low-THC varieties, and testing of fields to determine THC content.

History

The first records of hemp cultivation and use are from China, where the species most likely originated (Ehrensing). Migrating peoples likely brought hemp to Europe where, by the 16th century, it was widely distributed, cultivated for fiber, and the seed cooked with barley or other grains and eaten (Dempsey, 1975).

Hemp reportedly was first grown in the New World in Chile in 1545 (Blade). The Puritans brought hemp to New England in 1645 as a fiber source for household spinning and weaving, but it never rivaled flax in importance. Cultivation spread to Virginia and, in 1775, to Kentucky, where the crop grew so well a commercial cordage industry developed. The hemp industry flourished in Kentucky, Missouri, and Illinois between 1840 and 1860 because of strong demand for sailcloth and cordage by the U.S. Navy. However, increased production of cotton in the South, due to the development of the cotton gin, and imports of cheaper jute and abaca eventually displaced most domestic hemp production (Dempsey, Ehrensing).

In 1937, Congress passed the Marijuana Tax Act, which placed all *Cannabis* culture under the regulatory control of the U.S. Treasury Department. The Act required the registration and licensing of all hemp growers with the Federal Government in an effort to restrict production of marijuana in the United States (Dempsey; Rawson, 1992; Ehrensing).

During World War II, when imports of abaca and jute were unavailable, the Government instituted an emergency program to produce hemp as a domestic substitute. USDA's Commodity Credit Corporation contracted with War Hemp Industries, Inc., a quasi-official organization, to produce planting seed and fiber. Production peaked in 1943 and 1944. After the war, production rapidly declined as imports resumed and legal restrictions were reimposed. A small hemp fiber industry continued in Wisconsin until 1958 (Dempsey, Ehrensing).

Industrial Hemp in Canada

In 1998, Health Canada permitted 259 farmers to grow hemp on 6,180 acres, mostly in Ontario and Manitoba (Health Canada, June 1998; Health Canada, June 1999). As of June 1999, Health Canada had issued 674 hemp production licenses, allowing cultivation on 35,000 acres. Manitoba accounted for over half of the acreage, followed by Saskatchewan and Ontario (Hansen-Trip, 1999). Actual acreage under cultivation was lower because of a wet spring in western Canada, lack of certified seed, and license delays (Hanks, Fall 1999). Most of the production was for seed, especially in western Canada.

Gardner and White (1998) and Hanks (Fall 1999) profile the leading Canadian companies involved in hemp production and processing. Most process seed or oil using existing facilities. Two Manitoba companies, Hemp Oil Canada and Fresh Hemp Foods, have their own presses. Only two companies, Ontario-based Hempline, Inc. and Kenex Ltd., operate fiber processing facilities.

Plant Characteristics and Growing Requirements

Cannabis sativa L. is often referred to as true hemp to distinguish it from other fiber crops. These include *Musa textilis* (abaca or manila hemp), *Agave sisalina* (sisal hemp), and *Crotalaria juncea* (sunn hemp).

Cannabis sativa is normally dioecious, meaning the species has separate male and female plants. Monoecious varieties, with the male and female flower parts on the same plant, have been developed in a number of countries through breeding and selection (Dempsey, Ehrensing). Several countries, such as France, the Netherlands, Hungary, Romania, and China, have ongoing breeding programs. The industry is seeking high-yielding strains that are low in THC and meet various end-use needs. For example, breeders are looking for fiber lines that are high in primary fiber yields (for pulping), extra-fine fibers (for textiles), and cellulose content (for biomass fuel) and for seed lines with various seed sizes (for easier hulling and assorted food uses), special amino acid profiles (for human and animal feeds), and specific components in the oil for industrial uses (such as industrial lubricants) (Vantreese, 1998).

Hemp is sensitive to day length; the plant matures (sets seed) as days get shorter in the fall. Since production has historically been concentrated in northern temperate regions, industrial hemp varieties have been selected to mature in early fall (Blade; Reichert, 1994).

Industrial hemp can be grown as a fiber, seed, or dual-purpose crop. Hemp is a bast fiber plant similar to flax, kenaf, and jute. The interior of the stalk is hollow, surrounded by a pith layer of woody fibers called hurds (fig. 1). Outside the cambium layer, where cells grow and differentiate, is the phloem or parenchyma layer, which contains the long cells known as bast fiber. Hemp seeds are smooth and about one-eighth to one-fourth of an inch long. The seeds usually contain from 29 to 34 percent oil. The oil is similar in composition to drying oils such as linseed and tung and consists primarily of three fatty acids: linoleic (54-60 percent), linolenic (15-20 percent), and oleic (11-13 percent) (Ehrensing). Both the fiber and seed can be used in a wide range of applications (fig. 2).

Industrial hemp grows well in areas where corn produces high yields (Ehrensing). It can be grown on a variety of soils, but it does best on loose, well-drained loam soils with high fertility and abundant organic matter. Plants require plentiful moisture throughout the growing season, especially during the first 6 weeks (Dempsey; Blade; Baxter and Scheifele, 1999). Hemp also needs substantial amounts of available nutrients to produce high yields. Both Dempsey (1975) and Ehrensing (1998) review numerous fertilization studies and conclude that hemp requires liberal fertilization for high fiber yields.

Hemp diseases are not widespread and occur sporadically. They are usually caused by seed- and soil-borne fungi, which can be controlled by seed treatment before planting or by rotation (Dempsey). Under favorable conditions, hemp is very competitive with weeds so herbicides are generally unnecessary in hemp fiber production (Ehrensing). Due to lower planting densities, weed suppression may be less complete when hemp is grown for seed (Baxter and Scheifele).

Harvesting, Retting, and Fiber Separation

Harvesting and fiber processing differ depending on whether the crop is grown for high-quality textile fiber, for seed, or for fiber and seed. The Oregon study, *Feasibility of Industrial Hemp Production in the United States Pacific Northwest*, summarizes current information and research on hemp harvesting, retting, and fiber separation when the crop is grown for fiber (Ehrensing).

Harvesting

When grown for textile fiber, the crop is harvested when the fiber is at its highest quality. During World War II, tractor-drawn harvester-spreaders were used to cut hemp stems and lay them in windrows for field retting. After retting, a second machine was used to gather and tie the stems into bundles for pickup and delivery to the mill. A similar harvest system is still used in Europe, but with more modern, specialized equipment. Because these systems are designed to maintain the parallel alignment of hemp stems throughout harvest and processing in order to maximize the recovery of long textile fibers, the equipment has limited throughput capacity.

For seed, hemp is harvested when the seed is mature and ready for combining. When produced as a dual-purpose crop in countries such as France and Hungary, the seed is harvested near maturity with combines modified to cut high off the ground, and then the stems are harvested. The fiber from a dual-purpose crop is usually of lower quality and is often used in low-value applications such as pulp and paper. The 1998 crop in Canada was for dual production, and farmers found that the length and strength of hemp fibers were very rough on equipment during harvest (Gardner and White; Vantreese, 1998; Scheifele, 1999). In 1999, some Canadian farmers planted early flowering cultivars, which are shorter than traditional varieties and easier to combine (Baxter and Scheifele). The first Canadian-bred seed strain, which will be available next year in limited quantities, is also short (Hanks, Fall 1999).

Retting

If hemp or flax (linen) fibers are to be used in textiles and other high-quality applications, the bast fibers must be separated from the rest of the stalk. Retting is a microbial process that breaks the chemical bonds that hold the stem together and allows separation of the bast fibers from the woody core. The two traditional types of retting are field and water retting.

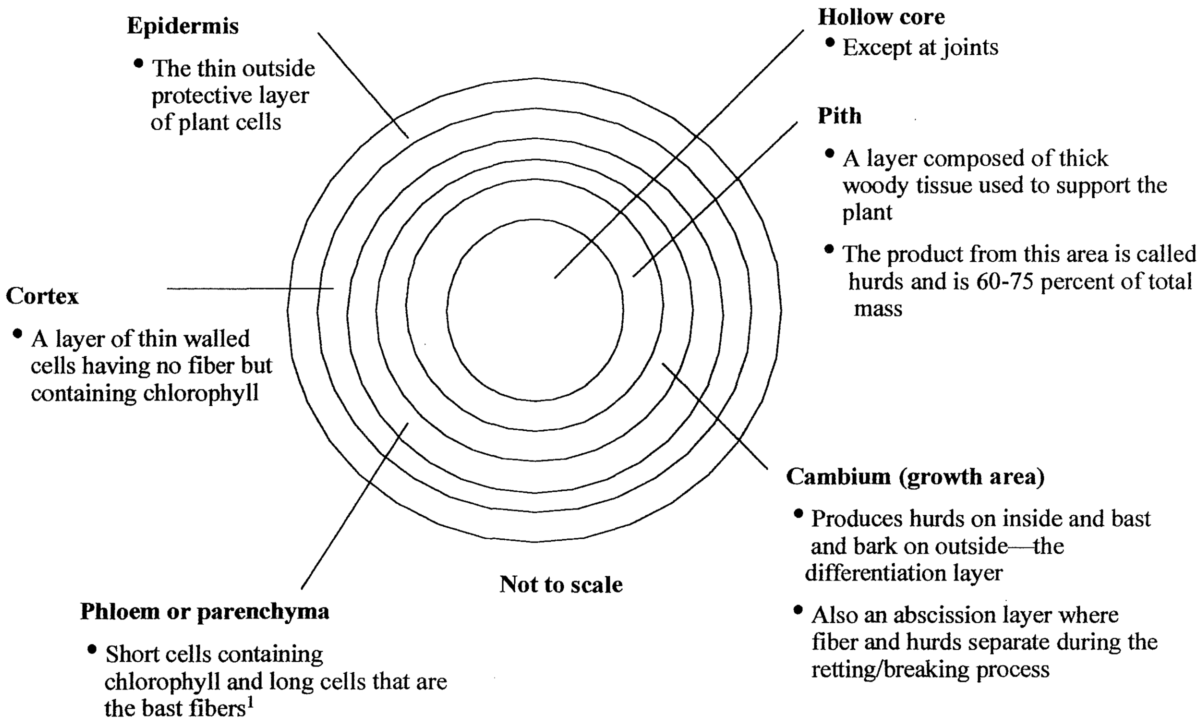
With field or dew retting, plant stems are cut or pulled up and left in the field to rot. Farmers monitor the process closely to ensure that the bast fibers separate from the inner core without much deterioration in quality. Moisture is needed for the microbial breakdown to occur, but then the weather must be dry enough for the stalks to dry for bailing. Although varying weather conditions affect the quality of fiber, field retting has been used extensively for hemp because it is inexpensive, mechanized, and does not use water.

Water retting produces more uniform and high-quality fiber, but the process is very labor- and capital-intensive. Stems are immersed in water (rivers, ponds, or tanks) and monitored frequently. Not only is this labor-intensive, farmers and/or workers must be knowledgeable about fiber quality. Also, the process uses large volumes of clean water that must be treated before being discharged. Water retting has been largely abandoned in countries where labor is expensive or environmental regulations exist. Most hemp fiber currently used in textiles is water retted in China or Hungary. Scientists speculate that improved microorganisms or direct use of enzymes may allow countries in Europe and North America to produce textile-quality bast fibers.

Fiber Separation

Once the stalks are retted, dried, and baled, they are brought to a central location for processing. With mechanical separation, in a process called breaking, stalks are passed between fluted rollers to crush and break the woody core into short pieces (called hurds), separating some of it from the bast fiber. The remaining hurds and fiber are separated in a process called scutching. Fiber bundles are gripped between rubber belts or chains and carried past revolving drums with projecting bars that beat the fiber bundles, separating the hurds and broken or short fibers (called tow) from the remaining long fiber (called line fiber). Fiber and hurds also can be separated with one machine called a decorticator (Kerr, 1998). Figure 3 presents a generalized schematic of plant and fiber yields, when grown

Figure 1. Cross section of a hemp stem



[1] Bast fibers are composed of primary bast fibers, which are long and low in lignin, and secondary bast fibers, which are intermediate in length and higher in lignin.

Source: Oliver and Joynt, p. 3.

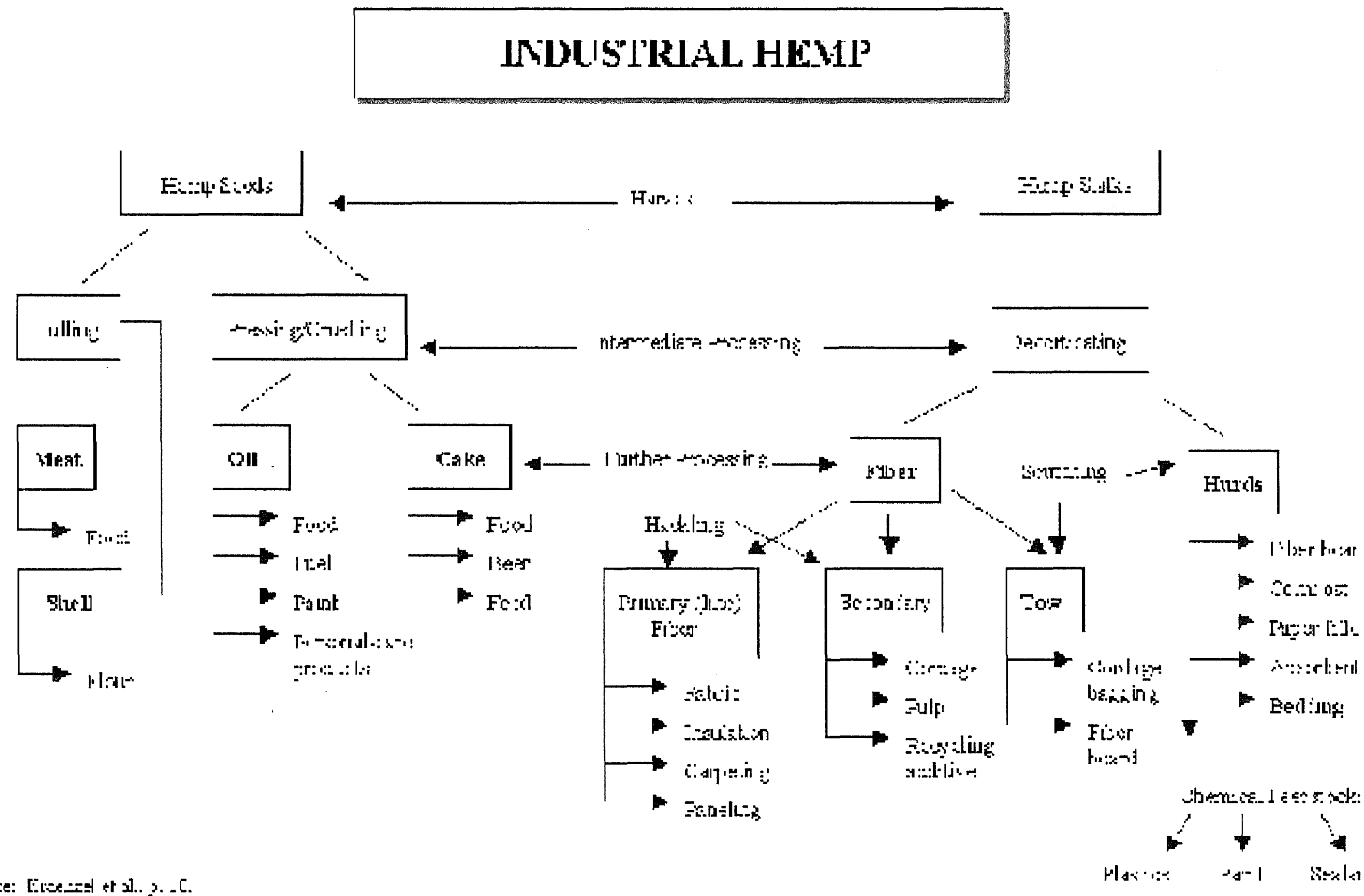
for high-quality textile fiber, from harvest through to fiber separation.

Although partially mechanized, these procedures are functionally identical to traditional hand methods of preparing hemp line fiber and tow for twisting into twine or rope or for spinning into yarn. Not only are these methods time consuming, they require skilled workers and considerable investment in capital equipment.

It is also possible to mechanically convert virtually all of the bast fiber directly into tow using flax breaking and tow processing machinery. This eliminates traditional scutching and allows processing of randomly oriented baled straw. Compared with scutching machinery, tow-processing equipment usually has higher throughput, requires fewer and less skilled workers, and costs less. However, a tow processing system cuts all of the bast fiber into short lengths, making it appropriate only for lower value uses, such as pulp and paper, instead of textiles.

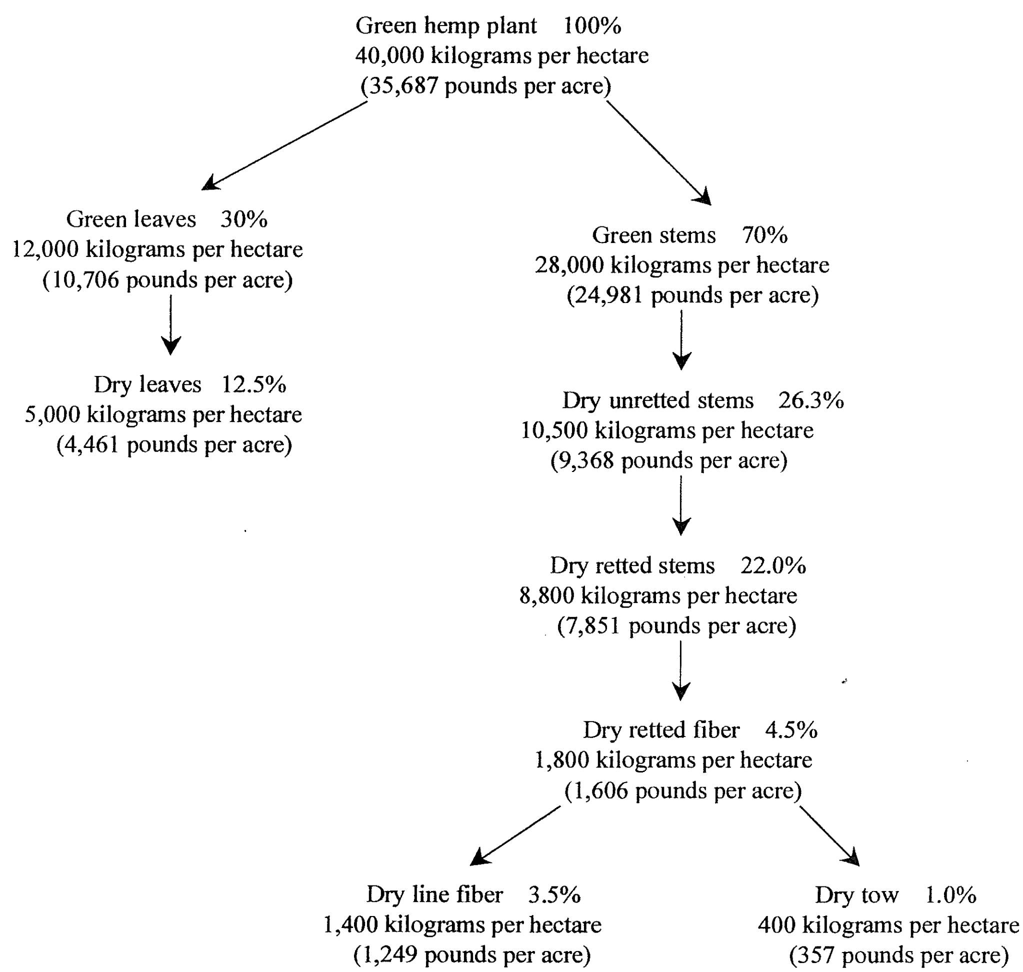
Research in Europe has sought methods for separating the bast fiber that bypass traditional retting and scutching. Steam explosion and ultrasound are under investigation in Germany, but the processes produce only short fiber. Neither technology has moved beyond laboratory or pilot scale trials. For hemp to be a viable fiber crop in the United States, modern hemp harvesting and processing methods would need to be developed.

Figure 2. Hemp products flowchart



Source: Kraenzel et al., p. 10.

Figure 3. A typical breakdown of the green- and dry-plant components of hemp grown for fiber



Note: Although these stem and fiber yields are from 1970, they illustrate how bast fibers are only a small portion of total crop yields.

Source: Dempsey, p. 82.

U.S. Hemp Fiber and Fabric Imports

No data are available on imports or exports of hemp seed and oil into the United States, but data do exist on hemp fiber, yarn, and fabrics.

Imports of raw hemp fiber have increased dramatically in the last few years, rising from less than 500 pounds in 1994 to over 1.5 million pounds for the first 9 months of 1999 (table 1). Yarn imports also have risen substantially, peaking at slightly less than 625,000 pounds in 1997. The switch from yarn to raw fiber in the last 2 years probably reflects the development of U.S. spinning capacity. At least two companies are now spinning hemp yarn from imported fibers (Gross, 1997). According to industry sources, domestic spinning capacity for hemp was not available earlier in the decade. No direct information is available on the uses of the yarn, but it is likely used to manufacture apparel, household furnishings, and/or floor coverings.

A separate import code for hemp fabrics was added to the Harmonized Tariff Schedule in 1995, so only a few years of data are available. Imports more than doubled from over 222,000 pounds in 1995 to about 523,000 pounds in 1998. The volume dropped for the first 9 months of 1999, again probably reflecting domestic production of hemp-containing fabrics. China is the largest supplier of hemp fabric to the United States, followed by Hungary, Poland, and Romania. Data are not available on how much hemp clothing and household furnishings are imported into the United States.

Imports of tow and yarn waste have declined since the late 1980's and early 1990's and have varied from year to year (table 1). No direct information is available on the uses of hemp tow and yarn waste. However, both hemp and flax are bast fibers and flax tow and yarn wastes are byproducts of linen processing and spinning. Since the main use of flax tow and waste is in specialty papers, hemp tow and waste may be used for the same purpose.

The United States also exports hemp raw fiber, tow and yarn waste, and yarn. During 1997-99, hemp exports were around 10 percent of imports. The data for earlier years, however, are suspect as exports of raw fiber are unexplainably larger than imports.

A full discussion of world production and trade of hemp fiber and seed can be found in Charest (1998) and Vantreese (1998). Wang and Shi (1999) also review the decade-long decrease in world hemp fiber production and highlight China's critical role in declining world production and exports. Dempsey (1975) and Ehrensing (1998) provide historic information on world fiber production.

Table 1—U.S. hemp imports, by category, 1989-99

Year	Raw fiber	Tow and yarn waste	Yarn	Total fiber, tow/waste, and yarn	Fabric	Total[1]
			Pounds			
1989	0	166,200	0	166,200	na	166,200
1990	0	74,697	542	75,239	na	75,239
1991	1,900	127,429	132	129,462	na	129,462
1992	904	15,410	88	16,402	na	16,402
1993	0	121	16,848	16,969	na	16,969
1994	463	6,089	11,570	18,122	na	18,122
1995	14,844	7,754	8,181	30,779	222,495	253,274
1996	72,991	43,568	12,899	129,458	291,517	420,975
1997	193,535	13,340	624,682	831,557	451,174	1,282,731
1998	708,918	73,471	149,447	931,836	522,789	1,454,625
1999[2]	1,587,674	35,170	65,927	1,688,771	201,650	1,890,421

na = Not available. A separate import code for hemp fabrics was added in 1995.
[1] Includes fabric for 1995-99.
[2] January to September.

Source: U.S. Department of Commerce, Bureau of Census.

Fiber Markets

Currently, the markets for bast fibers like industrial hemp include specialty textiles, paper, and composites. Cordage markets have long disappeared, as natural fibers have largely been replaced by plastic and steel (Miller, 1991; Orgel and Ravnitzky, 1994). In recent years, Canada, Australia, and a few European countries, including the Netherlands and Germany, have researched industrial hemp as a possible fiber for textile and paper production. Hungary and China currently are the major producers of high-quality, water-retted hemp textile fibers (Ehrensing). Small specialty pulp and paper mills in Britain, Spain, and Eastern Europe process flax, hemp, and other specialty fibers. Other potential uses of hemp bast fiber include molded automobile parts and as a replacement for fiberglass. In addition, hurds are utilized in various applications such as animal bedding.

Industry sources and some academic studies, such as Thompson et al. (1998) and Gardner and White (1998), cite numerous current and potential uses for hemp bast fiber and hurds. For these applications to develop or expand, hemp will have to compete with current raw materials and manufacturing practices. In the market for nonwood fibers, hemp would have to compete with cotton, flax, abaca, sisal, and other nonwood fibers in terms of fiber characteristics, fiber quality, and price. The U.S. market for hemp fibers is, and will likely remain, a small, thin market. Changes in price or quantity could be more disruptive and have a greater adverse impact on market participants than would be the case in a larger market. For example, small increases in world hemp fiber and tow production caused export prices to fall by half to a world average of 35 cents per pound in 1996 (Vantreese, 1998). See Appendix II for a discussion and some examples of oversupply in small, thin markets.

Specialty Textiles

According to Ehrensing (1998), hemp textile production is based primarily in Asia and central Europe. Most hemp fiber used in textiles is water-retted in China or Hungary. However, water retting has been largely abandoned in countries where labor is expensive or environmental regulations are enforced. Several companies in Poland also make hemp yarn and fabrics (Gardner and White). A small market based on hemp textiles imported from China, Poland, and Hungary has developed in North America and western Europe during the 1990's. In the last few years, a couple of U.S. companies have begun producing hemp yarns and/or fabrics (Gross, Gardner and White).

The current, low-end size of the U.S. market for hemp raw materials may be defined as the equivalent domestic production and acreage required to replace imports of hemp fiber, yarn, and fabric in 1999.[1] Reichert (1994) reports hemp fiber yields of 800 to 2,320 pounds of fiber per acre. Assuming a potential U.S. yield of 1,550 pounds of fiber per acre (midpoint of the range) and using linen yarn and fabric conversion factors (1.0989 and 1.1447, respectively), the total import quantity of hemp fiber, yarn, and fabric in 1999 could have been produced on less than 2,000 acres of land. Given the average size of farms in the United States (near 500 acres), just a few farms could have supplied the hemp fiber equivalent of 1999 import levels. Detailed data are not available on the amount of hemp seed or oil or the levels of hemp-containing clothing and household furnishings imported into the United States. Thus, this calculation understates the production capacity needed to replace all hemp product imports. Nevertheless, the calculation does demonstrate the small, thin nature of the market for industrial hemp and its products in the United States.

Hemp's closest competing fiber for textile uses—in terms of fiber production, processing, and characteristics—is linen, which is derived from textile flax. Textile flax is not grown in the United States, with demand met wholly by imports. While U.S. imports of hemp fiber, yarn, and fabric have increased dramatically in recent years, 1999 hemp imports (January-September) represented just 0.5 percent of U.S. linen yarn, thread, and fabric imports. However, the U.S. market for linen may indicate the longer term potential demand for hemp fiber and products. During 1989-99, imports of linen yarn, thread, and fabrics accounted for 62 percent of total linen imports (table 2). Linen apparel accounted for another 33 percent, with household furnishing and floor coverings taking up the remainder. The United States also exports a small amount of linen products (table 3).

A long-term, high-end size of the potential U.S. market for hemp fiber could be defined by considering the equivalent domestic production and acreage required

[1] Nine months of import data were extrapolated to estimate a full year of imports.

Table 2—U.S. linen imports, by category, 1989-99[1]

Year	Yarn, thread, and fabric	Apparel	Household furnishings	Floor covering	Total[2]
			1,000 pounds		
1989	388,036	178,957	1,799	9,555	578,347
1990	408,078	170,367	1,512	9,611	589,568
1991	368,383	177,722	3,137	10,812	560,054
1992	320,325	192,787	1,611	22,877	537,600
1993	321,186	193,040	914	22,286	537,426
1994	339,604	196,292	1,797	34,089	571,782
1995	368,778	163,492	3,171	35,736	571,177
1996	246,191	144,194	1,990	32,559	424,934
1997	329,590	154,634	1,835	36,846	522,905
1998	253,270	183,602	1,954	44,995	483,821
1999[3]	186,301	148,106	3,142	41,707	379,256

1 Estimated raw-fiber equivalent quantity contained in the products.
2 Does not include imports of raw fiber and tow/yarn waste.
3 January to September.

Source: Meyer.

Table 3—U.S. linen exports, by category, 1989-99[1]

Year	Yarn, thread, and fabric	Apparel	Household furnishings	Floor covering	Total[2]
			1,000 pounds		
1989	24,256	12,160	2,471	8,154	47,041
1990	32,727	15,794	4,267	12,011	64,799
1991	28,005	16,072	4,300	15,440	63,817
1992	30,755	14,878	3,274	15,431	64,338
1993	30,178	19,629	2,610	17,455	69,872
1994	35,511	23,038	2,457	14,569	75,575
1995	35,106	24,397	3,011	13,733	76,247
1996	39,681	27,745	2,729	14,844	84,999
1997	54,604	19,803	3,980	26,784	105,171
1998	56,282	19,976	3,738	22,906	102,902
1999[3]	48,045	16,598	1,733	14,093	80,469

1 Estimated raw-fiber equivalent quantity contained in the products.
2 Does not include exports of raw fiber and tow/yarn waste.
3 January to September.

Source: Meyer.

to replace both hemp and linen imports. The hemp fiber required to replace the equivalent level of hemp and linen fiber, yarn, and fabric imports in 1999 could have been produced on 250,000 acres—roughly 40 percent of 1997 tobacco acreage, 5 percent of U.S. oat acreage, or 0.4 percent of wheat acreage.

Hemp and linen are specialty textile fibers. Since 1980, linen and hemp together have accounted for less than 3 percent of world textile fiber production (table 4). Cotton and noncellulosic fibers are the dominant components. Worldwide production of hemp fibers decreased from a high of 569 million pounds in 1980 to 222 million pounds in 1995, a decline of 61 percent. A new data series was started in 1996, which does not

Table 4—World textile fiber production, 1980-98

Year	Rayon and acetate	Non-cellulosic fibers	Cotton	Wool (clean)	Silk	Flax	Hemp (soft)[1]	Total fibers
				Million pounds				
1980	7,147	23,095	31,427	3,675	123	1,389	569	67,425
1981	7,064	23,869	30,474	3,719	126	1,347	492	66,969
1982	6,493	22,368	31,993	3,656	121	1,437	459	66,603
1983	6,457	24,418	31,560	3,759	121	1,733	406	69,779
1984	6,605	26,023	42,552	3,831	123	1,512	443	71,669
1985	6,462	27,533	38,541	3,816	150	1,642	481	77,011
1986	6,304	28,499	33,880	3,924	139	1,605	485	80,688
1987	6,229	30,293	38,891	4,079	139	2,108	474	82,213
1988	6,385	31,784	40,514	4,202	141	2,039	465	85,530
1989	6,488	32,512	38,280	4,431	146	1,799	397	84,053
1990	6,079	32,838	41,808	4,359	146	1,570	364	87,164
1991	5,365	33,678	45,636	3,929	148	1,541	439	90,736
1992	5,130	35,629	39,650	3,794	148	1,484	432	86,267
1993	5,171	36,566	37,234	3,695	150	1,369	260	84,445
1994	5,087	39,549	41,229	3,437	152	1,261	209	90,924
1995	5,342	40,514	44,868	3,283	203	1,537	223	95,970
1996	5,004	43,887	43,219	3,289	194	1,448	139	97,180
1997	5,102	48,837	44,132	3,181	192	1,400	148	102,992
1998	4,817	50,135	40,629	3,120	192	1,424	152	100,469

[1] *Cannabis sativa*. Figures prior to 1996 include rough estimates for the former Soviet Union and Eastern Europe. A new data series was started in 1996 that does not include estimates from these regions.

Source: Meyer.

include production estimates from the former Soviet Union and Eastern Europe. During 1996-98, production averaged 146 million pounds, with China as the dominant producer.

According to industry sources, the fineness and quality of flax and hemp overlap depending upon growing conditions, variety, and how the crop is handled after harvesting. There is no industry consensus as to how closely the markets for the two fibers are allied (Gross). Nonetheless, with hemp fiber imports just 0.5 percent of linen imports, the near-term market potential for hemp in the United States (for domestic textile production) is closer to the low end of the 2,000- to 250,000-acre production-equivalent range. The general manager of Kenex Ltd. indicated that the 1999 supply of hemp fiber and seed from 35,000 Canadian acres has oversupplied the North American hemp market (von Sternberg, 1999).

Some people will buy hemp apparel and related items simply because they are made from hemp. This is probably a small but stable component of demand. A more volatile component is based on fashion trends and whether designers use hemp- or linen-containing fabrics in their designs. In the last few years, some famous designers, including Calvin Klein, Giorgio Armani, and Ralph Lauren, have included hemp fabrics in their clothing lines (Gross; *The Economist*, 1998; Copeland, 1999). Because of changing fashion trends, markets for specialty textile fibers tend to be cyclical. Cyclical markets would be more disruptive to fibers with small markets than to fibers with large market shares, such as cotton.

Hemp also is being used in the manufacture of household furnishings and floor coverings, particularly carpets (Gross; von Hahn, 1999). Competition with linen for traditional upholstery, drapery, and floor covering markets would depend on the fiber's quality and price.

A comparison of the import values for hemp and linen yarns reveals that hemp may be able to compete on price (table 5). From 1994 to 1998, the import value

Table 5—U.S. import value of linen and hemp yarns, 1989-99

Year	Linen yarn, single	Linen yarn, multiple	Hemp yarn
		Dollars/pound	
1989	2.47	6.76	na
1990	2.50	6.34	12.92
1991	2.38	5.33	21.19
1992	2.14	5.67	18.26
1993	2.38	4.61	1.34
1994	3.49	2.26	1.34
1995	3.73	2.24	2.89
1996	2.39	1.86	1.93
1997	3.14	2.62	1.01
1998	2.86	3.34	2.47
1999[1]	2.79	3.09	3.31

na = Not available.
[1] January-September.

Source: U.S.Department of Commerce, Bureau of Census.

of hemp yarn averaged $1.93 per pound, while the value for single- and multiple-strand linen yarn averaged $2.97 per pound. Information on yarn quality is not available, which may account for linen's higher value. Nevertheless, the value of hemp imports per pound, calculated by dividing the value of hemp yarn imports by the volume, has fluctuated widely since the early 1990's. During 1990-92, the value of hemp yarn ranged from $12.92 to $21.19 per pound. Between 1993 and 1999, the value ranged from $1.01 in 1997 to $3.31 for the first 9 months of 1999. The lower values in recent years may be to due to the increased volume of imports, enabling companies to spread their costs over more tonnage. Similar variations occurred in the import values of raw hemp fiber, which settled at around 40 cents per pound in 1997 and 1998.

Paper and Composites

The specialty and recycled paper markets are also possibilities for industrial hemp bast fibers. Specialty paper markets include currency, cigarette papers, filter papers, and tea bags. A number of companies in U.S. and European markets are selling paper that contains small amounts of hemp fiber, usually blended with less expensive nonwood fibers. These papers have gained some market acceptance as ecologically friendly or tree-free, but at present are considerably more expensive than wood-based paper (Ehrensing, Gardner and White). Within the mainstream pulp and paper market, fibers compete on quality characteristics, with cotton predominant among nonwood fibers, then flax, and then kenaf and other specialty fibers. Manufacturers are willing to pay more for specialty fibers if quality dictates. For example, abaca fibers retain their strength and form when wet, commanding a high price.

Rising wood prices and regulatory practices have promoted the growth of recycled pulp and paper. Therefore, a potential market may exist for agricultural fibers as an additive to strengthen paper made from recycled materials. Recent Dutch and German research suggests that industrial hemp may not be competitive in the specialty paper market, but may be used as a fiber supplement to recycled paper pulp.

In North America, use of nonwood fibers, such as hemp, in composites is still largely in research and development or the early stages of commercialization. Flax, kenaf, jute, hemp, and wheat straw—in combination with various resins—can be used to make composite board. Wheat straw is the dominant nonwood fiber in these applications (Glaser and Van Dyne, 1997). Hemp fibers could be desirable in this market because of their length and strength. Composites made using agricultural fibers are being developed in companies and research institutes in Europe, Canada, and the United States. The USDA Forest Service's Forest Products Laboratory is a leader in the research of nonwood fibers in composites. The percentage of the composites market captured by nonwood fibers in coming years will depend on economics and availability of raw materials.

Other Potential Uses

The *Economic Impact of Industrial Hemp in Kentucky* cites molded automobile parts and fiberglass replacement as potential uses for hemp bast fiber. Hemp fibers have been used in the manufacture of trunk liners and press-molded airbag parts for several BMW models. Kenex Ltd. has developed prototype molded car parts. Transit buses are being retrofitted in Florida with molded hemp parts for use in Orlando (Thompson et al.). In recent years, several automobile companies have investigated using nonwood fibers, such as hemp and kenaf, in the manufacture of molded car parts because they are lighter and more recyclable than current raw materials (Domier, 1998; Copeland). For nonwood fibers to gain a part of this market, they will have to be supplied in adequate quantities throughout the year at prices competitive with current raw materials.

The Kentucky report also suggests that hemp and other nonwood fibers could replace fiberglass in certain applications. The short fiber length and absorbent properties of these fibers would limit their use to replacing chopped fiberglass and in applications where moisture is not a problem. Given current market conditions, it can be assumed that synthetic fibers are the raw material of choice because of their properties (e.g., moisture resistance), their price, or both.

Hemp Hurds

In countries currently producing industrial hemp, hurds are sold for a variety of uses, including animal bedding, composites, and low-quality papers. According to Thompson et al. (1998), industrial hemp hurds appear to be price-competitive with wood chips, fine wheat straw, and other types of bedding used for high-value racehorses. Hemp hurds are favored over cheaper alternatives since they are more absorbent, and thus, reduce illness. Companies in England, France, and the Netherlands are making horse bedding from hurds. Some members of the racehorse industry in Kentucky have expressed interest in using hemp hurds (Patton, 1999). In addition, hurd-based cat litter is being sold in England, France, and Germany (Gardner and White). Since hurds are a joint product with the bast fiber, finding markets for hemp hurds may make the difference between a profitable and unprofitable industrial hemp enterprise.

Seed Markets

Thompson et al. (1998) estimated the demand for hemp seed by asking seed processing firms in the United States and Canada how many tons they purchased per month. They estimated North American demand at 1,300 tons at an average price of 39 cents per pound. Given yields in Germany of 1,000 pounds per acre, it would take 2,600 acres to satisfy the estimated demand for hemp seed. Ehrensing (1998) found bulk hemp seed prices at about 45 cents per pound, with strong demand. Hanks (Fall 1999) reports an average Canadian seed price of 41 cents per pound (60 cents Canadian) in 1999, but states that many observers fear overproduction of hemp in western Canada may bring crop prices down. In comparison, during the 1994/95-1998/99 marketing years, soybean, canola, and flaxseed prices averaged 10, 11, and 10 cents per pound, respectively (Ash, 1999).

According to Vantreese (1998), export prices of hemp seed have been extremely volatile in the last 20 years, mainly due to the variability of Chinese exports. China began producing and exporting hemp seed in large quantities in 1986, causing world prices to fall from 25 cents in 1985 to 15 cents per pound in 1986. In 1991, China stopped exporting hemp seed and prices nearly doubled in 1992. Prices peaked in 1995 at 41 cents a pound. During the 1990's, increased EU production of hemp also increased the demand for seed stock for planting, thereby raising export values.

Hemp seeds can be used as a food ingredient or crushed for oil and meal. The seed contains 20 percent high-quality, digestible protein, which can be consumed by humans, animals, and birds (Vantreese, 1998). The seed is approximately 29 to 34 percent oil by weight. The oil can be used both for human consumption and industrial applications (fig. 2). Due to the high content of polyunsaturated oils, it is fairly unstable and becomes rancid quickly unless preserved. The meal (seed cake) contains 25 to 30 percent protein and can be used in food and animal feed (Vantreese, 1998; Hinz, 1999).

Companies are using hemp seed in their products. Natural-product magazines, such as the *Natural Food Merchandiser* and *Organic & Natural News*, have advertised products containing hemp ingredients such as roasted hulled seed, nutrition bars, tortilla chips, pretzels, and beer. At least two breweries in the United States, as well as breweries in Canada, Germany, and Switzerland, make hemp beer (*The Economist*; Gardner and White; Louie, 1998). One article touts hulled hemp seeds as more shelf-stable than flax and more digestible than soybeans and finds the seed in snacks, spreads, salad dressings, cheese, and ice cream (Rorie, 1999). The market potential for hemp seed as a food ingredient is unknown. However, it probably will remain a small market, like those for sesame and poppy seeds. Some consumers may be willing to pay a higher price for hemp-seed-containing products because of the novelty, but otherwise hemp seed will have to compete on taste and functionality with more common food ingredients.

Currently, a trendy use of hemp oil is for body-care products, such as lotions, moisturizers, shampoos, and lip balms (Marshall, 1998; Rorie). For example, The Body Shop, a British-based international skin products company, began selling hemp-oil-containing products about 2 years ago in the United States. In June 1999, the company reported that those seven or eight products now account for 10 percent of total sales. However, to meet this demand, The Body Shops imports only 12 tons of organic hemp seed oil a year into the United States (Patton).

Hemp oil is also sold in health food stores as a nutritional supplement. The oil is mechanically (cold) pressed from the seed to maintain its quality and integrity. According to one industry participant, cold-pressed hemp oil has a dark green color and nutty flavor (Hemp-Agro). It contains roughly the same ratio of linoleic and linolenic acids that would be found in a nutritionally balanced diet (Marshall, Hinz). In addition to these two essential fatty acids, hemp oil contains 1 to 4 percent gamma-linolenic acid (GLA). GLA is also available from evening primrose and borage oils that, because of their unpleasant taste, are sold only in capsule form (Marshall, Hemp-Agro).

The market for hemp oil is limited by a number of factors. First, mechanical crushing produces a lower oil yield than crushing combined with solvent extraction. Nor does hemp oil undergo degumming and bleaching as do many other vegetable oils. Some consumers prefer an oil that has been processed without chemicals, but others may dislike hemp oil's color or taste. Second, the oil is high in unsaturated fatty acids, which can easily oxidize, so it must be kept in dark-colored bottles and has a limited shelf life. Like flax and safflower oils, which also are highly unsaturated,

Table 6—U.S. use of selected vegetable oils in industrial applications, 1978/79-1998[1]

Year[2]	All fats and oils[3]	Linseed oil	Tung oil	Linseed and tung oils
		Million pounds		
1978/79	4,443.9	207.5	13.5	221.0
1979/80	4,216.1	160.0	15.7	175.7
1980/81	4,163.2	127.6	16.6	144.2
1981/82	3,721.0	92.7	14.6	107.3
1982/83	3,649.6	97.6	12.2	109.8
1983/84	3,982.1	121.2	19.7	140.9
1984/85	3,665.0	166.0	12.4	178.4
1985/86	3,571.3	176.9	11.6	188.5
1986/87	5,990.6	280.8	12.2	293.0
1987/88	4,098.1	159.3	14.8	174.1
1988/89	3,805.4	154.9	7.7	162.6
1989/90	3,509.8	110.5	8.9	119.4
1991	3,745.1	95.8	6.4	102.2
1992	3,727.9	154.4	7.3	161.7
1993	3,646.2	125.8	11.2	137.0
1994	4,307.5	124.3	9.3	133.6
1995	3,760.2	112.8	20.2	133.0
1996	3,588.7	98.6	21.3	119.9
1997	3,889.8	83.0	19.4	102.4
1998	3,695.4	79.4	14.3	93.7

1 Includes soaps, paints, varnishes, resins, plastics, lubricants, fatty acids, and other products.
2 Crop year runs from October 1 to September 30. Annual totals reported on a calendar year basis beginning in 1991.
3 Includes castor oil, coconut oil, tallow (beef fat), lard (pork fat), linseed oil, rapeseed oil, soybean oil, tall oil, and tung oil.

Source: U.S. Department of Commerce, Bureau of Census.

hemp oil should not be used for frying. Third, to be used as a salad oil, it will have to be tested by the U.S. Food and Drug Administration and found "generally recognized as safe." In Canada, hemp foods are now regulated as novel foods, a legislative category developed primarily for products containing genetically modified organisms (Hanks, Fall 1999).

As a drying oil, hemp oil would have to compete with manmade chemicals and plant-based oils, such as linseed and tung oils, in industrial applications. As with industrial uses of all plant and animal oils and fats, use of linseed and tung oils has fluctuated in the last two decades, with no apparent upward or downward trend (table 6). Hemp oil would have to compete on functionality and price with current raw materials in these established industrial markets.

Potential U.S. Production and Processing

Potential yields and processing methods, along with farmer costs and returns, are important considerations when evaluating industrial hemp as a potential U.S. crop. Revenue is dependent on yields and market prices. Generally, the lower the market price, the greater the yield must be for producers to break even or make a profit. In addition, U.S. experience with kenaf and flax may lend insights into the processing hurdles hemp may face in the United States.

Possible Yields

The Oregon study summarizes hemp yields reported by researchers from various countries since the 1900's (Ehrensing). Early in this century, U.S. dry-stem yields ranged from 2 to 12.5 tons per acre, but averaged 5 tons per acre under good conditions. Research trials in Europe during the last four decades had dry-matter yields that ranged from 3.6 to 8.7 tons per acre. In the Netherlands, research trials during the late 1980's reported dry-stem yields of 4.2 to 6.1 tons per acre. Recent commercial production in England produced average dry-matter yields of 2.2 to 3 tons per acre on several thousand acres over several years. Experimental production in Canada during 1995 and 1996 yielded 2.5 to 3 tons of dry stems per acre. According to the study, some of the variation in yield can be attributed to different measurement practices. For example, European authors generally report total above-ground dry matter, including stems, leaves, and seed, versus the dry-stem yields reported by other researchers.

Vantreese (1998) reports that hemp seed yields have increased dramatically in recent years. In 1997, world average yields reached 876 pounds per acre. Yields ranged significantly, from a high of 1,606 pounds per acre in China, where the seed is consumed, to 595 pounds per acre in France, where much of the production is certified planting seed. In Germany, current seed yields are about 1,000 pounds per acre (Thompson et al.), while those in Eastern Europe range from 350 to 450 pounds per acre (Mackie, 1998). In Canada, seed yields in 1999 averaged 800 pounds per acre (Hanks, Fall 1999).

Processing

In addition to the uncertainty about yields, there is some question as to whether hemp fibers can be profitably processed in the United States. As was outlined earlier, the technologies used to process hemp fiber have not changed much and they require capital investment and knowledgeable workers. Research is under way to streamline harvesting, retting, and fiber separation, but those technological breakthroughs have yet to occur. Traditional retting and fiber-separation

Table 7—Estimated enterprise costs for hemp production in Kentucky, 1994

Costs	Fiber[1]	Seed	Certified seed
		Dollars/acre	
Variable costs:			
Seed (pounds)	(40) 80.00	(10) 20.00	(10) 20.00
Fertilizer	33.58	33.58	33.58
Lime (tons)	(1) 10.82	(1) 10.82	(1) 10.82
Fuel, oil (hours)	(4.5) 16.02	(2.2) 12.22	(2.2) 12.22
Repairs	9.35	17.60	17.60
Interest	7.93	4.24	4.24
Total	184.12	98.46	98.46
Fixed costs[2]	46.08	41.25	64.84
Operator labor[3] (hours)	(8) 56.00	(8) 56.00	(10) 70.00
Total enterprise costs	286.20	195.71	233.30

[1] Harvested and sold as raw stalks.
[2] Depreciation, taxes, insurance.
[3] At $7 per hour.

Source: McNulty.

processes—both labor and resource intensive—could limit the ability of U.S. hemp producers to compete against major suppliers such as China, Hungary, Poland, and Romania.

Specialty oilseed crushing mills that could accommodate hemp seed do exist in the United States. According to the *Soya & Oilseed Bluebook*, companies in North Dakota, Minnesota, Georgia, and North Carolina mechanically crush flaxseed, borage, safflower, canola, sunflowerseed, crambe, peanuts, and cottonseed (Soyatech, 1999).

Estimated Costs and Returns

Both the 1995 Kentucky Task Force report (McNulty) and the 1998 Kentucky impact analysis (Thompson et al.), as well as the Oregon and North Dakota studies (Ehrensing, Kraenzel et al.), present estimated costs and returns for hemp production. All include estimates for fiber (stalk) production. The 1995 Kentucky, 1998 Kentucky, and North Dakota reports also present estimates on seed production. In addition, most of the studies compare the estimated hemp costs and returns to those for other crops.

The Kentucky Task Force estimated total costs—which include variable costs, fixed costs, and operator labor—to be $286 per acre for hemp fiber, $196 for seed, and $233 for certified seed (table 7). These costs were comparable to 1993 estimated expenses for producing corn and double-crop wheat/soybeans in Kentucky (table 8). The analysis assumed that hemp grown for fiber would be harvested and sold as raw stalks on a dry-weight basis. Various sources priced raw, dry defoliated stalks at $60 to $125 per metric ton. Yields were assumed to range from 7 to 15 metric tons per hectare (2.8-6.1 metric tons per acre), based largely on European studies. Thus, potential returns for hemp fiber ranged from a low price/low yield estimate of $170 per acre to a high price/high yield return of $759 per acre (table 8). With estimated production expenses of $286, net returns for hemp for fiber ranged from -$116 to $473 per acre. Returns for hemp seed were estimated to range from $60 to $800 per acre. Given costs of production at $196 per acre, net returns ranged from -$136 to $604 per acre (McNulty).

The Oregon report also estimated costs and returns for hemp grown for fiber, using typical costs associated with irrigated field corn in the Pacific Northwest (table 9). Variable and fixed costs for hemp were estimated at $371 and $245 per acre, respectively. The dry-matter yield was assumed to be 5 tons per acre, which is consistent with the higher average yields reported in Western Europe using well-adapted cultivars. A price of $75 per dry ton was based on the price of wood chips in the Pacific Northwest, as it was anticipated that the fiber could be used by local composite and paper companies. Given this yield and price, gross

Table 8—Estimated costs of production and returns for various crops in Kentucky, 1993 or 1994

Crop[1]	Yield per acre	Return per acre	Estimated cost per acre: Variable	Fixed	Labor	Total	Net return per acre
			Dollars				
Fiber hemp[2]	2.8-6.1 metric tons	170-759	184	46	56	286	-116 to 473
Hemp seed[3]	na	60-800	98	41	56	196	-136 to 604
Corn grain	110 bushels	231	155	46	32	233	-2
Wheat/soybeans (double crop)	45/28 bushels	300	149	44	37	230	70
Tomatoes (for processing)	27 tons	2,430	1,278	154	231	1,663	767
Burley tobacco	2,500 pounds	4,375	1,905	626	700	3,231	1,144

na = Not available.
[1] For all crops except hemp, source is University of Kentucky, Department of Agricultural Economics crop budgets for 1993.
[2] Various sources priced dry, defoliated stalks at $60 to $125 per metric ton.
[3] One source estimated returns at $60 to $171 per acre for seed (for oil and feed), while another estimated seed returns at $800 per acre (2,000 pounds per acre at 40 cents per pound).
Source: McNulty.

Table 9—Estimated production budget for hemp in the Pacific Northwest[1]

Item	Dollars/acre	Dollars/ton (dry weight)
Variable costs:		
Cultural		
Tillage and planting	40.00	8.00
Hemp seed	34.00	6.80
Fertilizer and application[3]	85.00	17.00
Irrigation	62.00	12.40
Total	221.00	44.20
Harvest[4]		
Forage chopper ($3/ton)	15.00	3.00
Raking ($1.50/ton)	7.50	1.50
Baling, large square bales ($9.80/ton)	49.00	9.80
Loading and trucking ($3.00/ton)	15.00	3.00
Total	86.50	12.80
Miscellaneous		
Operating capital interest	29.78	5.96
Pickup	7.68	1.54
Farm truck	6.34	1.27
General overhead	20.00	4.00
Total	63.80	12.76
Total variable costs	371.30	69.76
Fixed costs:		
Land rent	150.00	30.00
Insurance, machinery and equipment	3.00	0.60
Irrigation system, depreciation and interest	44.00	8.80
Machinery and equipment, depreciation and interest	48.00	9.60
Total	245.00	49.00
Total production costs	616.30	118.76
Gross income (yield = 5 tons/acre)[5]	375.00	75.00
Net projected returns	-241.30	-43.76

[1] Budget was developed using typical costs associated with irrigated field corn in the Pacific Northwest. Production practices were chosen to maximize stem dry-weight yield for possible production of composite wood products or paper. [2] 25 pounds/acre at $1.36/pound. The assumed cost of hemp seed is the average of prices reported for commercially available European hemp varieties. Cost of shipping from Europe was not included. [3] 600 pounds/acre 16-16-16 at $250/ton. [4] Based on cost of operating silage corn harvesters and local cost of raking and baling hay and grass seed straw. No costs associated with retting, such as additional irrigation, are included. [5] The dry matter yield is assumed to be 5 tons/acre, which is consistent with the higher average yields reported in Western Europe using well-adapted hemp cultivars. An assumed price of $75 per dry ton was used in the analysis since prices for wood chips in the Pacific Northwest have risen over the past decade and this trend is expected to continue.

Source: Ehrensing.

revenue would be $375 per acre and net returns would be -$241 per acre (Ehrensing).

The Oregon report presents a sensitivity analysis of net returns based on various yields and potential market prices (table 10). Most of the net returns remain negative except under the highest yield/price combinations. The analysis was further refined to see if dual production was any more profitable. The cost of combine seed harvest, $20 per acre, was added to variable costs, and stalk yields were lowered to 2.5 tons per acre with a price of $75 per ton. Again, most of the net returns are negative except for the highest yield/price combinations (table 11) (Ehrensing).

The 1998 Kentucky report estimates costs and returns for hemp grown for fiber (straw), seed (grain), certified seed, and both fiber and seed (table 12). The cost esti-

Table 10—Estimated net return per acre from hemp production in the Pacific Northwest at various price and yield levels

Yield (tons per acre)	Price (dollars/ton) 50	75	100	125
	Dollars/acre			
3	-431.70	-356.70	-281.70	-206.70
4	-399.00	-299.00	-199.00	-99.00
5	-366.30	-241.30	-116.30	8.70
6	-333.60	-183.60	-33.60	116.40
7	-300.90	-125.90	49.10	224.10

Source: Ehrensing.

Table 11—Estimated net return per acre from dual-purpose hemp production in the Pacific Northwest at various seed prices and yield levels[1]

Seed price (dollars/pound)	Seed yield (pounds/acre) 500	750	1000
	Dollars/acre		
0.30	-255	-181	-106
0.35	-231	-143	-56
0.40	-206	-106	-6
0.45	-181	-68	45
0.50	-156	-31	94
0.55	-131	7	144

[1]The cost of combine seed harvest, $20 per acre, was added to variable costs. Hemp stem yield was assumed to be 2.5 tons per acre with a price of $75 per ton. Other assumptions are the same as those used for table 9.

Source: Ehrensing.

Table 12—Estimated growing costs and returns for industrial hemp in Kentucky using 1997 technology, yields, and, prices[1]

Item	Fiber[2]	Seed[2]	Certified seed	Fiber and seed[2]
		Dollars/acre		
Variable costs:				
Seed (pounds)	(50) 125.00	(10) 25.00	(10) 25.00	(50) 125.00
Fertilizer	45.01	45.01	45.01	45.01
Herbicides	0.00	10.95	10.95	0.00
Lime (tons)	(1) 12.12	(1) 12.12	(1) 12.12	(1) 12.12
Fuel, oil (hours)	(4.5) 18.43	(2.2) 14.06	(2.2) 14.06	(2.2) 22.25
Repair	16.14	30.38	30.38	23.12
Interest	8.38	5.24	5.24	8.94
Storage	5.00	5.00	5.00	5.00
Transport to processor	27.20	8.00	5.60	24.00
Total	257.28	155.76	153.36	265.44
Fixed costs[3]	50.27	45.00	70.73	75.05
Operator labor[4] (hours)	(8) 56.00	(8) 56.00	(10) 70.00	(9) 63.00
Total enterprise costs	363.55	256.76	294.09	403.49
Stalk revenue	680.00	60.00	60.00	450.00
Stalk yield	3.4 tons/acre	0.5 tons/acre	0.5 tons/acre	2.25 tons/acre
Price per ton	200/ton	120/ton	120/ton	200/ton
Seed revenue	na	416.91	840.00	273.00
Seed yield	na	1,069 lbs/acre	700 lbs/acre	700 lbs/acre
Price per pound	na	0.39/pound	1.20/pound	0.39/pound
Total revenue	680.00	476.91	900.00	723.00
Profit	316.45	220.15	605.91	319.51

na = Not applicable.
[1] Figures are based on estimates in McNulty (1995) and updated to 1997 based on the increased costs of growing corn. Also, herbicide, storage, and transport-to-processor costs were added; estimates for repair were increased by 50 percent; 50 pounds of hemp seed per acre were assumed for cultivating hemp for fiber rather than 40 pounds.
[2] Referred to in the report as straw and grain.
[3] Fixed costs include depreciation, taxes, and insurance.
[4] At $7 per hour.

Source: Thompson et al.

mates are based on the 1995 Kentucky report and updated to 1997 with some modifications. The yields used in the analysis are from Germany. The prices, based on import prices and/or prices paid in Canada, were estimated to be 39 cents per pound for seed, $1.20 per pound for certified seed for planting, and $200 per ton for hemp stalks. The residual stalks from seed production were estimated to fetch $120 per ton. Total costs ranged from $257 to $403 per acre. According to the report, these cost estimates are consistent with those made by Reichert (1994), by Kenex Ltd., and from German cultivation data (Thompson et al.).

Estimated revenue ranges from $477 per acre for seed to $900 per acre for certified seed. Thompson et al. admit that the very high returns calculated in these estimates cannot be sustained. While most of their discussion focuses on why the price of certified seed will decrease, little attention is given to stalk prices. The price they used for stalks is the first-year (1998) price offered by Kenex Ltd., the Ontario firm contracting for hemp acreage, which is not representative of long-term stalk prices. With new crops, firms often have to offer farmers an initial premium to induce them to experiment with a new crop and to compensate them for lower initial yields and the forgone returns of a conventional crop. Thus, many of the revenue estimates likely overstate average annual returns. Given the high estimates, it is not surprising that when compared with conventional field crops, hemp net

Table 13—Estimated returns to land, capital, and management per acre for industrial hemp and common Kentucky crops, 1997

Crop	Estimated return to land, capital, and management
	Dollars/acre
Hemp, seed only	220.15
Hemp, fiber only	316.45
Hemp, seed and fiber	319.51
Hemp, certified seed only	605.91
Grain sorghum, conventional tillage	10.51
Wheat, reduced tillage	14.24
Continuous corn	75.71
Popcorn, reduced tillage	78.25
Soybeans, no-till, rotation following crop	102.20
No-till corn, rotation following soybeans	106.48
White corn, rotation following soybeans, reduced tillage	135.84
Alfalfa hay	141.34
Barley/no-till soybeans, double-crop following corn	158.09
Wheat/no-till soybeans, double-crop following corn	158.43
Grass legume hay, round bales	161.56
Dark air-cured tobacco	182.48
Dark fire-cured tobacco	1,104.87
Burley tobacco, baled, nonirrigated	1,563.48

Source: Thompson et al.

returns were higher than those for all the selected crops except tobacco (table 13).

The costs and returns in the North Dakota report are based on a dual-purpose crop in Ontario, Canada. Information from Vantreese (1997) was used as the basis for the three price/yield scenarios. Prices ranged from $5.51 to $6.80 per bushel for seed and from $40.44 to $51.45 per ton for fiber (table 14). Yield estimates ranged from 14.3 to 23.8 bushels of seed per acre and 2.5 to 3 tons of fiber per acre. Total costs were estimated at $175 per acre, while potential revenue ranged from $180 to $316 per acre, resulting in net returns of $5 to $142 per acre. The return for the low-price/low-yield hemp scenario was comparable to those for most of the comparison crops in the study. Only irrigated potatoes had higher net returns than any of the three hemp scenarios (Kraenzel et al.).

Among the studies, total costs ranged from $175 for North Dakota to $616 in Oregon (table 15). A lot of the variation can be attributed to differences in fixed costs. For example, fixed costs in the Kentucky studies, which do not include land rent, are estimated at $75 per acre or below. In the Oregon report, fixed costs are $245 per acre, including land rent and irrigation-system depreciation. When land and irrigation costs are removed, fixed costs drop to $51. Also, when land rents, estimated at $65 to $75 (Vantreese, personal communication), are added to the Kentucky estimates, fixed costs range from $106 to $150. The estimates also may differ due to varying assumptions about production practices and may reflect different cost structures among the States. The Oregon study did cite high land costs as one reason hemp production may not be viable in the Pacific Northwest (Ehrensing).

Table 14—Estimated costs and returns for hemp and other crops in North Dakota, 1998

Crop	Average yield	Average price	Total revenue	Total costs	Net returns
	Per acre	*Dollars/unit*	*Dollars/acre*		
Low-price/low-yield hemp[1]	14.3 bushels; 2.5 tons	$5.51/bushel; $40.44/ton	179.96	174.63	5.33
Average hemp[1]	19 bushels; 2.75 tons	$6.16/bushel; $45.96/ton	248.13	174.63	73.49
High-price/high-yield hemp[1]	23.8 bushels; 3 tons	$6.80/bushel; $51.47/ton	316.29	174.63	141.65
Corn grain[2]	54 bushels	2.25	121.50	159.70	-38.20
Spring wheat[2]	31 bushels	3.71	115.01	117.32	-2.31
Confectionery sunflowers[2]	1,080 pounds	0.131	141.48	140.62	0.86
Malting barley[2]	50 bushels	2.41	120.50	115.02	5.48
Irrigated potatoes[2]	32,500 pounds	0.045	1,462.50	1,017.59	444.91

[1] Estimates are for a dual-purpose crop in Ontario, Canada.
[2] From projected 1998 crop budgets for Northeast North Dakota.

Source: Kraenzel et al.

Table 15—Comparison of estimated costs and returns for hemp from the various State studies

Report	Variable costs	Fixed costs[1]	Operator labor	Total costs	Revenue	Net returns
			Dollars/acre			
1995 Kentucky:						
Fiber	184	46	56	286	170 to 759	-116 to 473
Seed	98	41	56	196	60 to 800	-136 to 604
Certified seed	98	65	70	233	na	na
Oregon:						
Fiber	371	245	na	616	375	-241
1998 Kentucky:						
Fiber	257	50	56	364	680	316
Seed	156	45	56	257	477	220
Certified seed	153	71	70	294	900	606
Fiber and seed	265	75	63	403	723	320
North Dakota:						
Fiber and seed	na	na	na	175	180 to 316	5 to 142

na = not available.

[1] In the two Kentucky studies, fixed costs include depreciation, taxes, and insurance. In the Oregon study, fixed costs include land rent ($150), irrigation-system depreciation and interest ($44), machinery depreciation and interest, and insurance.

None of the cost estimates include costs for monitoring, licensing, or regulating hemp production. These external expenses would be part of the cost of producing industrial hemp and could be borne by taxpayers or passed on to growers and/or processors. According to Thompson et al. (1998), Kenex Ltd. estimates that Canadian farmers will pay US$50 annually for a background check and to obtain the satellite coordinates for their hemp fields (fields are monitored via satellite as part of the Canadian program).

The studies also present a range of revenue estimates, which is not surprising given the uncertainty about demand and expected market prices. Overall, it seems questionable that U.S. producers could remain profitable at the low end of the estimated net returns. In addition, given the thinness of the current U.S. hemp fiber market, any overproduction could lead to lower prices and lost profitability.

U.S. Experience With Kenaf and Flax

Both kenaf and flax can be legally grown in the United States. Their recent production history may lend additional insights into the potential for hemp in the United States.

Kenaf is a relatively new crop. It can be grown in many parts of the United States, but it generally needs a long growing season to produce the necessary yield to make it a profitable crop. With a long growing season, like that found in the southern United States, kenaf can reach a height of 12 to 18 feet and produce 5 to 10 tons of dry fiber per acre annually. An estimated 8,000 acres of kenaf was grown in the United States in 1997, up from 4,000 acres in 1992 and 1993. Primary production areas are Texas, Mississippi, Georgia, Delaware, and Louisiana (Glaser and Van Dyne). Processing and product technology for kenaf-based pulp and for about six other markets have been developed, but markets must be established in each geographic area since the core fraction is very low density and expensive to ship.

Flax is grown in the United States in small quantities. Production is almost totally oilseed varieties (for linseed oil). Textile or linen flax has not been grown commercially in North America for 40 years (Domier). The United States does not produce textile flax for several reasons. First, the market for linen is very small compared with other natural fibers like cotton, which accounts for nearly one-third of U.S. fiber mill use. Linen textile imports have accounted for an annual average of 2 to 3 percent of the quantity of all fibers consumed in the United States (mill use plus net textile trade). Additionally, since 1989, linen textile imports as a percentage of total textile imports have consistently fallen from 12 percent to 4 percent in 1998 and 1999. The market remains small because the economics of producing textile flax is not very price/cost competitive. As noted earlier, many inefficiencies continue to exist in this industry, particularly the methods of harvesting and processing. Because of the length of the fiber and the variation in quality, U.S. mills are reluctant to use textile flax. Some recent developments, however, have allowed the use of textile flax waste on cotton-spinning systems. Also, a flax fiber mill reopened in Quebec in December 1997, and research and development activities are occurring in Alberta, Connecticut, Maine, Oregon, and Saskatchewan (Domier; Hanks, Fall 1999).

State Study Findings

Each of the three 1998 studies focused on different aspects of supply and/or demand. Since Kentucky was a major producer of certified hemp seed in the past, it is one of the main markets mentioned in the 1998 study. Also, the horse racing industry in the State could be a significant buyer of hemp hurds for animal bedding. North Dakota has an oilseed crushing industry. Thus, the North Dakota study concluded that the largest market opportunity for the State may be hemp seed oil. The Oregon report concentrated on fiber production because of the pulp and paper industry in the Pacific Northwest. (Summaries from each of the reports are in Appendix III.)

All three of the studies do mention hemp's benefits as a rotation crop. As stated in the Oregon report, industrial hemp may provide an excellent rotation crop for traditional crops to avoid outbreaks of insect and disease problems or to suppress weeds (Ehrensing). The North Dakota report further states that hemp rebuilds and conditions soils by replacing organic matter and providing aeration through its extensive root system (Kraenzel et al.).

The Kentucky Task Force had a broad mandate to examine legal, agronomic, and economic aspects of hemp production. In 1995, the majority of the Kentucky Task Force concluded that legal prohibition of *Cannabis* cultivation was the overriding obstacle to reintroduction of fiber hemp production in Kentucky. Significant progress on agronomics, marketing, or infrastructure development is unlikely, and of relatively little importance, unless legal issues are resolved (McNulty).

The North Dakota report takes a different position. Since industrial hemp may have potential as an alternative rotation crop, the report recommends that the North Dakota Legislature consider action that would allow controlled experimental production and processing. This would allow collection and analysis of necessary baseline production, processing, and marketing data. At the same time, the concerns and costs of law enforcement agencies could be addressed (Kraenzel et al.).

Conclusions

Current markets for bast fibers like industrial hemp include specialty textiles, paper, and composites. Hemp hurds, the inner woody portion of the plant stem, are used in various applications such as animal bedding, composites, and low-quality papers. As joint products, finding viable markets for both hemp bast fiber and hurds may increase the chances of a successful business venture. Hemp industry sources and some academic studies cite many potential uses for hemp fiber and hurds. However, for these applications to develop or expand, hemp will have to compete with current raw materials and manufacturing practices. The U.S. market for hemp fibers is, and will likely remain, a small, thin market. Changes in price or quantity could be more disruptive and have a greater adverse impact on market participants than would be the case in a larger market.

Since there is no commercial production of industrial fiber hemp in the United States, the "size" of the market can only be gauged from hemp fiber and product imports. The near-term, low-end size of the U.S. market for hemp as a textile fiber might be defined by considering the domestic production and acreage required to replace imports of hemp fiber, yarn, and fabric in 1999. Assuming a potential U.S. yield of 1,550 pounds of fiber per acre and using linen yarn and fabric conversion factors, the estimated import quantity of hemp fiber, yarn, and fabric in 1999 could have been produced on less than 2,000 acres of land. Given the average size of farms in the United States (near 500 acres), just a few farms could have supplied the hemp fiber equivalent of 1999 import levels.

As a specialty bast fiber, hemp's closest competing textile fiber is linen. A longer term, high-end size of the potential U.S. market for hemp fiber could be defined as domestic production and acreage required to replace hemp and linen imports. The hemp fiber required to replace the equivalent level of hemp and linen fiber, yarn, and fabric imports in 1999 could have been produced on 250,000 acres—roughly 40 percent of 1999 tobacco acreage, 5 percent of U.S. oat acreage, or 0.4 percent of wheat acreage.

Despite the similarities between hemp and linen, there is no industry consensus as to how closely the markets for the two fibers are allied. But since hemp fiber imports were just 0.5 percent of linen imports during the first 9 months of 1999, the near-term market potential for hemp in the United States for domestic textile production is closer to the low end of the 2,000- to 250,000-acre production-equivalent range. Moreover, the absence of a thriving textile flax (linen) production sector in this country (despite no legal barriers) suggests that hemp, flax's close cousin in fiber uses and in production techniques, will be unable to sustain adequate profit margins for a large production sector to develop.

Thompson et al. (1998) estimate imports of hemp seed into North America at 1,300 tons. Given yields in Germany of about 1,000 pounds per acre, it would take 2,600 acres to satisfy the demand for hemp seed. As with fiber imports, it would take only a few average-sized farms to meet this demand. Hemp seeds can be used directly as a food ingredient or crushed for oil and meal. Hemp seeds and flour are being used in nutrition bars, tortilla chips, pretzels, beer, salad dressings, cheese, and ice cream. The market potential for hemp seed as a food ingredient is unknown. However, it probably will remain a small market, like the markets for sesame and poppy seeds. Some consumers may be willing to pay a higher price for hemp-seed-containing products because of the novelty, but otherwise hemp seed will have to compete on taste and functionality with more common food ingredients.

Hemp oil is being used as an ingredient in body-care products, such as lotions, moisturizers, and shampoos, and sold in health food stores as a nutritional supplement. The market for hemp oil is limited by a number of factors. First, mechanical crushing produces a lower oil yield than crushing combined with solvent extraction. Nor does hemp oil undergo degumming and bleaching as do many other vegetable oils. Some consumers prefer an oil that has been processed without chemicals, but others may dislike hemp oil's color or taste. Second, the oil is high in unsaturated fatty acids, which can easily oxidize, so it is not used for frying, must be kept in dark-colored bottles, and has a limited shelf life. Third, to be used as a salad oil, it will have to be tested by the U.S. Food and Drug Administration and found "generally recognized as safe." Last, as a drying oil, hemp would have to compete on functionality and price with current raw materials, such as linseed and tung oils, in established industrial markets.

Several States have published reports or authorized agronomic and economic feasibility studies of hemp production. The four reports summarized here have focused on different aspects of supply and/or demand. Their estimates of hemp costs and returns reflect these various focuses, as well as different assumed production practices and costs. However, the widest range of estimates exhibited among the reports is for stalk and seed yields and prices—not surprising given the uncertainty about hemp production and current and potential hemp markets. Overall, hemp production was profitable only at the higher end of estimated yields and prices. It seems questionable that U.S. producers could remain profitable at the low end of the estimated net returns, particularly given the thinness of current U.S. hemp markets.

The market for hemp products might easily be oversupplied, as in Canada where the 35,000 acres of hemp produced in 1999 was seemingly more than the market could handle. The *Minneapolis Star Tribune* quotes the general manager of Kenex Ltd., Canada's biggest hemp processor, as saying "It's given us one hell of a glut of grain and fiber. There's been a major overestimation of the market that's out there" (von Sternberg).

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INFORMATION March 1998

COMMERCIAL PRODUCTION OF INDUSTRIAL HEMP

Effective March 12 , 1998, the commercial production (including cultivation) of industrial hemp is now permitted in Canada, under licences and authorizations, issued by Health Canada.

Industrial Hemp usually refers to varieties of the *Cannabis* plant that have a low content of THC (delta-9 tetrahydrocannabinol) and that are generally cultivated for fibre. Industrial hemp should not be confused with varieties of *Cannabis* with a high content of THC which are referred to as marijuana. The psychoactive ingredient in marijuana is THC.

Internationally, *Cannabis* is regulated by the United Nation's ***Single Convention on Narcotic Drugs***. Canada has signed and ratified this Convention. The ***Controlled Drug and Substance Act (CDSA)*** came into force effective May 14, 1997. The ***Industrial Hemp Regulations*** to the CDSA will permit the commercial cultivation of industrial hemp in Canada.

The Regulations control the activities relating to importation, exportation, possession, production, sale, provision, transport, sending, delivering and offering for sale of industrial hemp.

The Regulations define industrial hemp as the plants and plant parts of the *Cannabis* plant, whose leaves and flowering heads do not contain more than 0.3 percent THC. It includes derivatives of the seeds such as oil and seedcake. It does not include non-viable *Cannabis* seed, but it includes its derivatives.

It also does not include the mature stalks or the fibres derived from those stalks. This means that such fibres or the products made from the mature cannabis stalk may be imported, treated and sold in Canada.

The Regulations consist of the following components:

- Importers and exporters of industrial hemp, in the form of seed or viable grain, will be licensed. In addition to holding a licence they will also be required to obtain a permit for each shipment.

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- The importer must ensure that shipments of viable grain are accompanied by foreign certification. A list will be published by Health Canada indicating which countries are designated as having equivalent controls on the production of viable grain. Viable grain may only be imported from listed countries. This will ensure that viable grain imported will not produce a plant containing more than 0.3% THC.

- Seed growers will be restricted to a 0.4 hectare minimum plot size and will be required to demonstrate current membership in the Canadian Seed Growers Association as part of their licence application. Seed growers will be required to provide the number of hectares grown in the previous two years as part of their licence application.

- Plant breeders will not be restricted to minimum plot sizes. Persons applying for a licence as a plant breeder must be registered with the Canadian Seed Growers Association and may only cultivate industrial hemp under this regulatory framework. The pedigreed seed restriction which applies to growers in the year 2000 does not apply to plant breeders nor does the limitation to the *List of Approved Cultivars*.

- Growers for fibre or viable grain will require a licence before they can purchase seeds from a distributor or cultivate industrial hemp. Growers will be required to provide the number of hectares grown in the previous two years as part of their licence application.

- Only approved varieties of industrial hemp seeds, as listed on Health Canada's *List of Approved Cultivars* may be planted. Commencing January 1, 2000, only pedigreed seeds of approved varieties may be planted. Growers will be required to identify their fields, and maintain records of production and distribution.

- Licences and audit trails will also be required for processing activities such as pressing seeds into oil. All parties licensed or authorized will be required to identify a person resident in Canada who will be responsible for the licensed activities.

- To obtain a licence for the importation, exportation, production or sale of industrial hemp, applicants will be required to produce a police security check.

- Derivatives of seed or viable grain, such as oil and seed cake, will be exempted from the Regulations if there is evidence that the derivatives contain no more than 10 micrograms of delta-9-tetrahydrocannabinol per gram and carry appropriate labelling statements. Products made from derivatives of seed or viable grain will be exempted if there is evidence that each lot or batch contains no more than 10 micrograms of delta-9-tetrahydrocannabinol per gram.

- Importers and exporters of derivatives will be required to provide proof with each shipment that the shipment contains no more than 10 micrograms of delta-9-tetrahydrocannabinol per gram for each lot to ensure that the product is within the limit. Similarly products made from the derivatives of seed or viable grain must be accompanied with evidence that each shipment contains no more than 10 micrograms of delta-9-tetrahydrocannabinol per gram.

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- No person will be permitted to import or export a derivative or a product produced from a derivative that contains more than 10 micrograms of delta-9-tetrahydrocannabinol per gram.

- No person will be permitted to import or sell whole plants, including sprouts or the leaves, flowers or bracts of industrial hemp; or import, sell, or produce any derivative or any product made from a derivative of the above.

- Authorizations will be required for transportation, when products are transported outside the direction or control of a licence holder, or for possession for the purpose of testing for viability.

- No person shall advertise to imply that a derivative or product is psychoactive.

- Testing for the level of THC in leaves or in derivatives must be done by a competent laboratory according to standards defined by Health Canada.

Health Canada will continue to issue licenses for approved research studies related to the cultivation of hemp for industrial purposes.

Application Forms and relevant Guidance Documents, aimed at expediting the review of licences and authorizations for the commercial cultivation of industrial hemp and also for research licences, are available.

The documents are available from:

Internet: www.hc-sc.gc.ca/hpb-dgps/therapeut
Section: Hemp

or

Jean Peart, Manager, Hemp Project
Bureau of Drug Surveillance
Therapeutic Products Directorate
Address Locator 4103A, 122 Bank Street, 3rd Floor
Ottawa, Ontario, Canada, K1A 1B9
Phone: (613) 954-6524 FAX: (613) 952-7738
Internet: jean_peart@hc-sc.gc.ca

Copies of the *Controlled Drugs and Substances Act* are available from:

Internet: canada.justice.gc.ca/FTP/EN/Laws/

or

Canada Communications Group
Ottawa, Ontario
KlA 0S9
Telephone - (613) 956-4802

Appendix II

Oversupply of Small, Thin Markets

This appendix presents the general economic theory behind the operations of small, thin commodity markets and provides three case studies to illustrate the consequences of oversupply.

General Economic Theory

Agricultural commodities are generally homogeneous and undifferentiated. Small, thin (niche-like) markets may develop due to changes in demand, such as a shift in consumer tastes, or changes in supply, such as a new production technology, a new product, or a new use for a traditional product. Oversupply in small, thin markets can result from supply-side phenomena, demand-side phenomena, or both.

When the stimulus comes from the supply side, innovators may actually have to cultivate a market for their product. Provided that expectations about production efficiencies hold true, early firms that discover and serve the market are able to realize a significant return. However, the early firms may not be able to deter new entries. When new firms enter, they are not aware of the number of other new entrances or the extent to which original firms are expanding production. Total supply may increase by more than what firms expect, driving prices down. For less efficient firms, price may be below average cost and they will exit the market. As the market matures, information is exchanged among buyers and sellers and parties develop more accurate expectations of market behavior.

On the demand side, changes in consumer preferences may stimulate a new or added demand for a product. With expectations for continued growth in demand, producers respond to initial price incentives by entering the market. If demand does not expand as expected, the market finds itself oversupplied and prices decline.

In some cases, expectations about production efficiencies and future growth in demand combine to define a potential niche market. When one or both of the expectations fall short, the market becomes oversupplied and prices fall.

The extent of any price decline in small, thin markets that are oversupplied depends on secondary markets. The availability of a secondary market limits the price decline in the primary market; its absence sharpens the price decline and may force out all but the most efficient producers.

Losses incurred by producers/growers in an oversupplied niche market are a function not only of net returns to the production process, but of the size and specialized nature of the initial investment. Investment losses of the firms who exited the market will depend on the firms' sunk costs and the degree of specialization. If the initial investment was high, the losses may be greater. The degree of specialization is also important. If the plant and equipment can be used for another economic activity, some of the losses may be recouped or offset. However, if the equipment is specialized, the salvage value may be low.

Case Studies

A review of particular niche markets—poinsettias, emus, and mesclun—may serve to illustrate the issues involved in oversupply.

Poinsettias. *Large numbers of entrants led to oversupply. No secondary markets were available, so prices declined. Investment in specialized resources was minimal, so that many producers were able to shift resources to other horticultural products.*

U.S. growers produce more than $900 million of potted flowering plants annually, with poinsettias the most important. Only small quantities are imported from and exported to Canada. Poinsettias are a perishable product, demand is highly seasonal (November-December), and no secondary markets exist. Therefore, with imperfect knowledge about market supply and prices, growers can easily overproduce and prices can fall quickly, particularly since no secondary markets exist. Grower numbers probably peaked in 1992 and have since trended downward due to declining profit margins. Similar cases are found with other potted flowering plants, such as Easter lilies. Because production processes are similar, growers will typically switch to producing other flowering plants, foliage plants, or bedding and garden plants if profit margins decline.

Emus. *Significant investment in specialized resources (breeding stock), unexpectedly high production costs, and limited demand created substantial losses to growers.*

Production of ratites—ostriches, emus, and rhea—has occurred on a small scale in the United States for about 100 years. Starting about 1985, a few studies indicated that ratites might be efficient converters of feed. At the time, there was a known, albeit small, market for meat, hides, emu oil, eggs, and feathers, but it was expected to expand as production increased. This raised the price of breeding stock. U.S. ratite production entered into what is called the breeder phase. As more producers became convinced that ratites would be profitable, the demand for birds grew and the price of breeding stock skyrocketed. As long as producers were convinced that more breeding stock (and eventually products) could be marketed, the price remained very high. When the demand for products did not develop as growers had hoped, the demand for breeding stock declined and the price of breeding stock plummeted. Investment in the production of ratites, particularly in breeding stock, expanded much more rapidly than demand for products. Emus have received the most attention, as producers have let them run wild or killed the birds to avoid having to feed and care for them. In many cases, growers incurred significant losses when prices fell. There will probably continue to be a small market for some products and market size may even expand over time, but investment and production increased too fast, too soon.

Organic Mesclun. *Increased consumer demand for a popular new product led to high prices. Production costs and efficiencies for organic mesclun were not distinctly different from alternative (nonorganic) production practices. Nonorganic mesclun producers entered the market, supplies increased, and prices declined. Requirements for highly specialized investments were minimal. Firms with land certified for organic production could switch to other organic products with more profitable returns, which limited losses from oversupply of this market.*

For several years, USDA's Agricultural Marketing Service (AMS) has collected data on prices for organic mesclun mix (salad mix of baby lettuces, herbs, and greens) in the Boston wholesale market. Organic mesclun prices are higher than regular (nonorganic) mesclun, but the price premiums have declined in recent years. In 1996, regular mesclun from California or Arizona cost an average of $8.64 per 3-pound carton (ranging from $7.50 to $10.00) and organic mesclun cost $9.72 per 3-pound carton (ranging from $7.75 to $10.75). The monthly organic premium averaged 14 percent, ranging from 8 percent in November to 22 percent in December.

Mesclun is a relatively new commercial crop in the United States. Initially, mesclun was a very small market; it was produced organically and garnered high prices. Other producers—both organic and regular—entered the mesclun market, attracted by high returns. By 1996, only about 30 percent of the mesclun in the Boston wholesale market was organic. As production expanded, mesclun prices declined and the premium between organic and regular mesclun narrowed. Industry insiders say that as long as there is a large supply of regular mesclun, organic prices will continue to be low. The market will bear a very small premium for organic mesclun.

As the gap between organic and regular mesclun prices decreased, organic mesclun producers could remain in the market because variable production costs are not much higher than for regular mesclun. Since the lettuces and greens are harvested when quite small, they are not in the ground very long and are less prone to insect and disease problems than other organic crops.

The investment required to make land certified for organic production can be significant. Some industry experts think the organic share of the mesclun market will continue to decrease. But, since the production of organic mesclun requires little, or no, specialized investment, producers exiting the market will shift to other organic crops that yield a higher return on relatively expensive certified organic land.

Appendix III
State Report Summaries

Summary
Report to the Governor's Hemp and Related Fiber Crops Task Force
Commonwealth of Kentucky,
June 1995

- Most analysts forecast long-term increases in world demand for all types of fibrous materials, and some predict limitations in production capacity. New fiber crops, new industrial uses of nonwood fibers, and agricultural diversification in general are therefore subjects of widespread interest. Kentucky agriculture is not alone in efforts to pursue these possibilities, and will be required to compete with producers in other states and nations.

- Kentucky history, as well as recent research in other temperate zone countries, demonstrates that hemp can be produced in the Commonwealth. Selection of adapted varieties, crop management practices, harvesting technology and several other agronomic aspects may require a significant research and development effort if hemp is to be a large scale crop. Yet there is no reason to believe that these production issues are insurmountable.

- The historical advantages (for example: favorable climate, naturally fertile soils, labor supply) held by Kentucky hemp producers, particularly hemp seed producers, have been made somewhat less important by modern agronomic technology.

- Hemp and kenaf may have a slight advantage over certain other annual row crops with regard to potential environmental impacts. This might result from projected requirements for less pesticide and modest reductions in soil erosion.

- Currently, established markets for hemp in the U.S. are generally limited to specialty/novelty textiles, oils, foods, paper and other materials. The specialized nature of this market does not require competition with other fiber sources. The potential market size is difficult to predict, but it is unlikely to support the large acreage of a major new field crop.

- Bast fibers contribute an exceedingly small fraction of world textile fiber supply, which is overwhelmingly dominated by cotton. Increasing world demand and price for cotton in recent years has generated some interest in alternative fibers. However, extraction and processing of bast fibers for high-quality textiles is more difficult than for cotton. A large investment, and perhaps some technological innovation, will be required by the textile industry if bast fibers are to become competitive as mass market textiles.

- Use of annual fiber crops for most paper applications or for building materials, as a substitute for wood or recycled fiber, could create a very large but relatively low value market. Crop prices above $60/ton would probably be required to interest most producers; this price might preclude extensive competition in this market. Vast quantities of fibrous waste materials (sugar cane bagasse, straw) are available world wide and would also compete for such applications.

- A large and long-term USDA effort on kenaf has addressed many production and processing challenges. Infrastructure for significant utilization of kenaf fiber is beginning to develop in the southern U.S. The University of Kentucky College of Agriculture is actively investigating kenaf production. Development of this alternative fiber crop in Kentucky will be dependent on nearby location of processing facilities and a profitable market for farmers.

- Legal prohibition of *Cannabis* cultivation is the overriding obstacle to reintroduction of fiber hemp production in Kentucky. Significant progress on agronomics, marketing, or infrastructure development is unlikely, and of relatively little importance, unless legal issues are resolved. Legislative action would be required at both the state and federal level. Such consideration would likely receive strong diverse reactions from both private and public sectors.

Source: McNulty.

Summary
Feasibility of Industrial Hemp Production in the United States Pacific Northwest
May 1998

For many centuries hemp (*Cannabis sativa* L.) has been cultivated as a source of strong stem fibers, seed oil, and psychoactive drugs in its leaves and flowers. Environmental concerns and recent shortages of wood fiber have renewed interest in hemp as a raw material for a wide range of industrial products including textiles, paper, and composite wood products. This report assesses the agricultural feasibility of industrial hemp production in the Pacific Northwest (PNW).

Hemp is an herbaceous annual that develops a rigid woody stem ranging in height from 1 to over 5 meters (3 to 19 feet). Hemp stalks have a woody core surrounded by a bark layer containing long fibers that extend nearly the entire length of the stem. Plant breeders have developed hemp varieties with increased stem fiber content and very low levels of delta-9-tetrahydrocannabinol (THC), the psychoactive ingredient of marijuana.

Historically, hemp fiber was used mainly for cordage, but it can also be made into textiles, paper, and composite wood products. Demand for hemp cordage peaked in the late 1800's, and world hemp production has continuously declined since that time, except for brief increases during both World Wars. Hemp fiber has largely been replaced by relatively inexpensive natural and synthetic fibers.

Although hemp is well adapted to the temperate climatic zone and will grow under varied environmental conditions, it grows best with warm growing conditions, an extended frost-free season, highly productive agricultural soils, and abundant moisture throughout the growing season. When grown under proper conditions, hemp is very competitive with weeds, and herbicides are generally not required in hemp production. Although a number of insect pests and diseases have been reported on hemp, significant crop losses from pests are not common. High levels of soil fertility are required to maximize hemp productivity. Cultural requirements and production costs are quite similar to those of corn. Reported hemp yields range from 2.5 to 8.7 tons of dry stems per acre.

The climatic and soil requirements of hemp can be met in some agricultural areas of the PNW, however, hemp will almost certainly require irrigation to reliably maximize productivity in the region. The requirement for supplemental irrigation will place hemp in direct competition with the highest value crops in the PNW, limiting available acreage. Stem yields will have to be substantially higher than those previously recorded for hemp to be economically feasible in the PNW at current prices. It is unlikely that the investment needed to improve hemp production technology will be made until legislative restrictions are removed from the crop.

Source: Ehrensing.

Executive Summary
Economic Impact of Industrial Hemp in Kentucky
July 1998

In recent years, industrial hemp has been viewed worldwide as a versatile and environmentally friendly plant that has many industrial applications. Although it is currently grown in many European and Asian countries and even in Canada, industrial hemp is still prohibited from being grown in the United States.

This situation exists even though the current consumer and business environment in the United States may make industrial hemp cultivation and processing commercially feasible. Many consumers are starting to prefer products made from natural materials. The industrial hemp plant is a good source of natural raw materials for a number of products and is a superior source in some cases. Moreover, many farmers in Kentucky and throughout the nation are looking to alternative crops to replace their current crops, and some have touted hemp as an excellent rotation crop with much potential for agriculture.

Kentucky should be in a position to benefit from the establishment of an industrial hemp cultivation and processing industry in the United States. Historically, Kentucky has been a good location to grow hemp. Before hemp cultivation was outlawed, it had been a major crop in Kentucky and grew well in the climate. In the 1800's, Kentucky regularly accounted for one-half of the industrial hemp production in the United States. The climate, soil, and growing season in Kentucky also make the state a superior location for growing certified hemp seed to be planted by farmers raising an industrial hemp crop.

The Kentucky Hemp Museum and Library contracted with the University of Kentucky Center for Business and Economic Research to conduct an analysis of the potential economic impact of industrial hemp in Kentucky. This study looks at the different markets for hemp products, examining both the current markets in which foreign-grown hemp is being used, and potential or burgeoning markets that may have uses for industrial hemp.

In the report, we estimate costs for growing industrial hemp in Kentucky and provide information on potential prices farmers could expect for their hemp crop. We also compare the return from cultivating industrial hemp with the returns for other crops in Kentucky. In addition, we detail the costs of a hemp processing facility to separate the hemp into fiber and other materials. Finally, we estimate the potential jobs and earnings impacts of growing industrial hemp in Kentucky under several scenarios.

Among the key findings of this report are:

- A market for industrial hemp exists in a number of specialty or niche markets in the United States, including specialty papers, animal bedding, and foods and oils made from hemp.

- Additional markets could emerge for industrial hemp in the areas of automobile parts, replacements for fiberglass, upholstery, and carpets.

- Using current yields, prices, and production technology from other areas that have grown hemp, Kentucky farmers could earn a profit of approximately $320 per acre of hemp planted for straw production only or straw and grain production, $220 for grain production only, and $600 for raising certified seed for planting by other industrial hemp growers. In the long run, it is estimated that Kentucky farmers could earn roughly $120 per acre when growing industrial hemp for straw alone or straw and grain, and $340 an acre from growing certified hemp seed.

- Industrial hemp, when grown in rotation, may reduce weeds and raise yields for crops grown in following years. Several agronomic studies have found that industrial hemp was more effective than other crops at reducing selected weeds. One study found that industrial hemp raised yields by improving soil ventilation and water balance.

- The economic impact if Kentucky again becomes the main source for certified industrial hemp seed in the United States is estimated at 69 full-time equivalent jobs and $1,300,000 in worker earnings. The total economic impact in Kentucky, assuming one industrial hemp processing facility locating in Kentucky and selling certified seed to other growers, would be 303 full-time equivalent jobs and $6,700,000 in worker earnings. If two processing facilities were established in Kentucky, industrial hemp would have an economic impact of 537 full-time equivalent jobs and $12,100,000 in worker earnings. If one processing facility and one industrial hemp paper-pulp plant were established in Kentucky, industrial hemp would have an economic impact of 771 full-time equivalent jobs and $17,600,000 in worker earnings.

- These economic impact estimates reflect possible outcomes for Kentucky given a national industrial hemp industry that is focused in specialty niche activities that have been demonstrated to work in Europe. It is important to remember, however, that technologies are under development that may allow industrial hemp products to compete in bulk commodity markets. The economic impacts that would occur if these technologies were found to be commercially feasible would be substantially greater than those identified in this report.

Source: Thompson et al.

Executive Summary
Industrial Hemp as an Alternative Crop in North Dakota
July 1998

This preliminary study reports on current efforts to define existing world markets and possible United States markets for industrial hemp as well as resulting economic feasibility should production be legalized. A large percentage of the information available on industrial hemp is by non-agriculturists. This indicates a need for North Dakota to continue working with its agricultural counterparts to bring this potential alternative crop into the agricultural research domain.

- The industrial hemp world market consists of over 25,000 products in nine submarkets: agriculture, textiles, recycling, automotive, furniture, food/nutrition/beverages, paper, construction materials, and personal care. These products are made or manufactured from raw materials derived from the industrial hemp plant: fiber, hurds, and hemp seed/grain.

- World hemp fiber production has declined from over 400,000 tons in 1961 to 113,000 tons in 1996. India, China, Russia and Korea are the major low cost producers. This constitutes about 250,000 acres under production worldwide. Preliminary figures for 1997 indicate that this downward trend continues.

- A revitalization of industrial hemp may be occurring as indicated by projected increased demand (retail sales) from $75 million in 1997 to $250 million by 1999 worldwide (*Wall Street Journal*, April 24, 1998). Various reasons that would explain this phenomenon include technological advances in processing, an increase in pricing, or interpretation of existing information.

- The largest market opportunity for North Dakota identified in this report may be hemp seed oil. This opportunity was also identified by the University of Kentucky (July 1998).

- North Dakota may have a comparative advantage because a state of the art multi-oil processing facility already exists that is capable of processing hemp seed.

- Hemp hurds appear to be price competitive with wood chips, fine wheat straw, other types of animal bedding, and other high-end pet needs. Hurds may also be a complement or substitute material in strawboard production.

- Certified seed production is a market opportunity.

- Initially, hemp appears to be comparable to barley. However, a 1998 Kentucky study projects higher returns from $220.15 per acre for producing hemp seed for crushing to $605.91 for certified seed.

- Historically, imported jute and abaca were intense competitors with American industrial hemp.

- Law enforcement agencies have legitimate concerns about their ability to enforce laws regulating industrial hemp production. Advances in biotechnology such as terminator genes may create solutions.

- Recommendations. Since industrial hemp may have potential as an alternative rotation crop, it is recommended that the North Dakota Legislature consider action that would allow controlled experimental production and processing, then, necessary baseline production, processing, and marketing data could be collected and analyzed. For example, all new enterprises would require a critical threshold volume in order to succeed in terms of economic profit. What is the volume and the acreage required to produce it? At the same time the concerns and costs of law enforcement agencies could be addressed.

Source: Kraenzel et al.