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Illegally Green: Environmental Costs of Hemp Prohibition

By Skaidra Smith-Heisters

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By Skaidra Smith-Heisters

Regulation of *Cannabis sativa L.* is complicated by the fact that there are two common varieties of the plant with very different properties: the agricultural variety, known by the common name hemp, and the pharmacological variety, marijuana. Prior to prohibition in the United States, industrial hemp was the subject of considerable excitement and speculation. The same is true today, as lawmakers and stakeholders in many states are considering the potential for reintroducing industrial hemp into the domestic economy.

The environmental performance of industrial hemp products is of particular interest because, to a large degree, environmental inefficiencies impose costs on society as a whole, not just on the producers and consumers of a specific good. Many commodities which came to replace traditional uses of industrial hemp in the United States in the last century and a half have created significant environmental externalities.

Assessments of industrial hemp as compared to hydrocarbon or other traditional industrial feedstocks show that, generally, hemp requires substantially lower energy demands for manufacturing, is often suited to less-toxic means of processing, provides competitive product performance (especially in terms of durability, light weight, and strength), greater recyclability and/or biodegradability, and a number of value-added applications for byproducts and waste materials at either end of the product life cycle. Unlike petrochemical feedstocks, industrial hemp production offsets carbon dioxide emissions, helping to close the carbon cycle.

The positive aspects of industrial hemp as a crop are considered in the context of countervailing attributes. Performance areas where industrial hemp may have higher average environmental costs than comparable raw materials result from the use of water and fertilizer during the growth stage, greater frequency of soil disturbance (erosion) during cultivation compared to forests and some field crops, and relatively high water use during the manufacturing stage of hemp products.

Overall, social pressure and government mandates for lower dioxin production, lower greenhouse gas emissions, greater bio-based product procurement, and a number of other environmental regulations, seem to directly contradict the wisdom of prohibiting an evidently useful and unique crop like hemp.

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Part 1

Introduction

One of the world's oldest agricultural crops, *Cannabis sativa L.*, is the most politicized plant in U.S. history. The cultivation of *Cannabis sativa* has been perceived to be so essential to national security, that at various times the government has mandated that farmers grow it, and at other times strictly forbade it. Regulation of the species is complicated by the fact that two varieties with very different properties are common: the agricultural variety of *Cannabis sativa*, known as hemp, and the pharmacological variety, marijuana. Both have been the subject of intense debate in the United States for roughly 70 years.

As an industrial crop, hemp has been grown either for the long fibers located in the outer layer of the plant's stem (called "bast" fiber), for seed, or a combination of both. A secondary product of the high-quality bast fiber crop is the internal core, or "hurd," consisting of short fibers and cellulosic biomass with a variety of industrial applications. Seed is also a valuable commodity derived from multi-purpose hemp crops.

Cotton, petroleum-based textiles, and forest products have replaced industrial hemp in some markets it formerly dominated. For traditional textile uses, hemp is probably most comparable to flax, though jute and kenaf are other notable bast fiber competitors. In emerging industrial applications, including composite construction materials and biofuel sources, hemp is often evaluated for performance alongside these and other biomass and oilseed crops, fiberglass, and agricultural byproducts like wheat straw.[1]

Often the politics of *Cannabis* regulation have been so severe that science was sacrificed by factions intent to either demonize or idolize the plant. Hemp cultivation is not permitted in the United States today, and this creates speculation about what value hemp would have on the market as an industrial feedstock if U.S. laws were changed. The environmental performance of industrial hemp products is of particular interest because, to a large degree, environmental inefficiencies impose costs on society as a whole, not just on the producers and consumers of a specific good. This study seeks to add to the discussion about hemp prohibition by comparing the performance of hemp to its substitutes in a few key industrial applications.

Part 2

History of Industrial Hemp in the United States

Used in sails, rigging, canvas, and ropes, hemp was so essential to industry and, in particular, the maintenance of the Navy and shipping fleet in 1776, that in *Common Sense* Thomas Paine cited the fact that “hemp flourishes even to rankness” first among the fledgling nation’s assets in the fight for independence. In the early years of the United States, paper and clothing derived from hemp were also prevalent.

Cultivation of hemp in the United States grew to a peak between 1840 and 1860, even while cheaper imported abaca and jute fibers gradually began to replace domestic hemp for some industrial uses.[2] Farm labor became more expensive after the end of the Civil War, increasing the competitive edge held by domestic cotton, the processing of which had become much more efficient with the invention of the cotton gin. As late as 1913, hemp was still used more extensively than any other bast fiber besides jute, and the United States Department of Agriculture (USDA) suggested that the crop’s lack of popularity with U.S. farmers was due to the high labor demands of the crop. The USDA botanist in charge of fiber plant investigations, Lyster Dewey, noted that any increase in the demand for hemp was met through imports.[3]

In 1859, near the peak of domestic industrial hemp production, another event occurred that would soon change both the politics and economics of U.S. industry: the drilling of the first oil well. Three years later, a federal tax was levied on alcohol to help pay for the Civil War. Though the target of the tax was purportedly beverage alcohol, it made fuel and industrial uses of alcohol prohibitively expensive—a condition which persisted, despite the repeal of the tax in 1906, through alcohol Prohibition from 1920 to 1933.[4] The result was exceptionally fast growth in the use of petroleum feedstocks in first fuel and then plastics. Petroleum-derived textiles diminished the market for domestic hemp even further.

The growing dominance of the petroleum industry had vocal critics at the turn of the century. Scientists Thomas Edison and George Washington Carver, engineer Rudolph Diesel, industrialist Henry Ford, chemist William Hale, and his father-in-law H.H. Dow (founder of Dow Chemical Company) were among those who championed bio-based fuels and plastics. Dewey at the USDA also tried to rally domestic hemp farmers, and in 1916 wrote, “Without doubt, hemp will continue to be one of the staple agricultural crops of the United States.”[5]

Differences between marijuana and hemp varieties of *Cannabis sativa*:

- Marijuana cultivated for drug value contains between 3 and 10 percent of the active ingredient, tetrahydrocannabinol or THC. Industrial hemp typically contains 0.3 percent or less of this active ingredient—as a result, it has no value as a drug.
- In drug cultivation, only female marijuana plants are grown, because their flowering parts contain the highest concentrations of THC. The plants are branching and bushy in order to maximize this flowering potential.
- The highest-valued fiber is derived from either male or monoecious hemp plants (plants that produce both male and female flowers on the same plant), which are planted very densely in order to encourage the growth of tall, straight stalks.
- Hemp grown for seed looks similar to marijuana. The two can be distinguished with a chemical test.
- If seed hemp and marijuana plants cross-pollinate, the resulting seed produces plants with THC levels in between the levels found in the parent plants. Growers of either plant should want to prevent this, and use a known genetic variety to grow each new crop.

Accounts of hemp acreage grown in this period are rough estimates at best, subject to numerous biases and inconsistent recordkeeping. A survey commissioned by the Federal Bureau of Narcotics reported that "from 1880 to 1933 the hemp grown in the United States had declined from 15,000 to 1,200 acres, and that the price of line hemp had dropped." [6] But the Bureau's surveys at the time also showed that the trend in hemp acreage was suddenly reversing, with just a few companies contracting for the 6,400 acres of hemp planted in 1934, increasing to 10,900 acres in 1937.[7] The markedly increased interest in hemp was a result of speculation that technological breakthroughs in the processing of hemp for fiber and the growing market for cellulose for use in paper, explosives, rayon, cellophane, and plastic products would open new markets for hemp. This speculation inspired *Mechanical Engineering* in 1937 to declare it "the most profitable and desirable crop that can be grown," and *Popular Mechanics* to call it the "new billion-dollar crop" a year later.[8]

Just as this renewed interest was growing in 1937, legislation purportedly enacted to curtail marijuana cultivation took hundreds of U.S. hemp farmers and their investors by surprise. The Marihuana Tax Act made "importation, manufacture, production, compounding, sale, dealing in, dispensing, prescribing, administering, and giving away of marihuana" subject to registration and transfer taxes. The majority of U.S. states had already passed laws making cultivation of *Cannabis* for anything but medical or industrial purposes illegal. Federal Bureau of Narcotics Commissioner Harry Anslinger assured farmers that the legislation would not affect them; the law specifically excluded industrial hemp from the definition of "marihuana."[9] After all, the USDA was researching the use of hemp hurds in the production of cellulose even at the time. Soon, however, it became clear that Anslinger intended to extend the taxes and penalties for violating the Act (up to $100 per ounce of marijuana and five years in prison) to include any hemp stalks that bore leaves.[10]

Material shortages as a result of World War II gave proponents of agricultural industrialism a last chance to make their vision a reality. By this time, hemp was no longer used in sails and rigging that had made it an essential wartime crop in earlier periods, but disruption of the supply of tropical fibers momentarily restored the need for hemp in a number of other applications. Enforcement of the Marihuana Tax Act was temporarily suspended and farmers were encouraged to grow hemp and flax as domestic substitutes for abaca and jute to supply the U.S. Navy. The need to replace foreign hemp imports during World War I had created a spike in domestic production reaching an estimated high of 42,000 acres planted in 1917—this time planting peaked at 178,000 acres in 1943.[11,12] Increases in domestic hemp production didn't outlast the war, however. Agricultural industrial feedstocks continued to lose importance as cheaper substitutes developed, and the government regulation of hemp through the Tax Act made it a particularly unattractive crop to farmers and investors.

Between 1958, when the last hemp crop was planted in Wisconsin, and 1999, when a permit was issued for experimental test plots in Hawaii, no hemp was legally grown in the United States.

Major producers of hemp today include China, Russia, Hungary and France, where hemp production has always been legal. In the late 1980s experimental field trials of industrial hemp were carried out in the Netherlands and in the 1990s, industrial hemp production was re-legalized in Great Britain, Germany, Austria, Switzerland, Canada, Australia and elsewhere.

Beginning in Kentucky in 1994, individual U.S. states began to introduce legislation authorizing feasibility studies for domestic industrial hemp production. To date, reports in Arkansas, Colorado, Hawaii, Illinois, Kentucky, Maine, Minnesota, Missouri, North Dakota, Oregon, Vermont, and Wisconsin have indicated potential for state production of industrial hemp.[13] At the request of the White House Office of National Drug Control Policy, these state-level studies were summarized in part in a report by the United States Department of Agriculture in 2000.[14] The focus of this bulk of research has been on economic feasibility (and, to a lesser extent, agronomic feasibility) and has relied on broad speculation about what domestic markets and enterprises would look like if industrial hemp production were allowed in the United States.[15] In all, more than half of the states in the nation have introduced, and one-third have approved, legislation concerning renewed research or cultivation of industrial hemp.

Part 3

Environmental Costs of Hemp Substitutes

The parallel histories of industrial grain alcohol and hemp, from early prevalence in domestic industrial applications to taxation, prohibition, and relative obsolescence, also share at least one broad-reaching environmental implication: elevated industrial emissions resulting from the replacement of these carbohydrates with hydrocarbon industrial feedstocks. Many commodities which came to replace traditional uses of industrial hemp in the United States in the last century and a half also carried considerable environmental baggage.

Cotton and polyester production are two good examples of industries that replaced industrial hemp. Both are high-performance materials with unique qualities. Polyester fiber manufacturing requires six times the average energy required to produce either cotton or industrial hemp fiber, generating particulate pollution, as well as carbon dioxide, nitrogen oxides, sulphur oxides, and carbon monoxide.[16] Cotton is one of the most water- and pesticide-intensive crops in the world.[17] The United States is the second largest producer of cotton, accounting for roughly a fifth of world production. Health effects due to pesticide use are a concern for both humans and wildlife, particularly bird and amphibian species. One researcher has estimated environmental and societal damages as a result of pesticide use in the United States at a value of $9.6 billion annually.[18] Because industrial hemp has far greater natural pest and weed resistance than cotton does, fewer inputs are needed for economic cultivation of this crop. Even new technologies that allow for more precise application of pesticides and genetic engineering for herbicide-tolerant and insect-protected cotton still leave cotton well outside the environmental performance range of hemp.[19]

Industrial hemp experts consider it a low-input, low-impact crop.[20] Inputs required for cultivation of any crop are an important environmental consideration because of the pollution created in their production and left behind from their use—from the manufacture of chemical fertilizers, herbicides and pesticides, to their shipment, storage, and delivery in the field. Depending on the irrigation source, crop irrigation can also represent a substantial energy input for any crop. For example, irrigating California’s crop land is the state’s single largest water commitment. Pumping for crop irrigation accounts for 5 percent of the state’s total energy use, and more than 90 percent of the state agricultural sector’s electricity use—though the dollar value of this cost is often subsidized by below-market water pricing for agricultural applications.[21]

Petroleum is inextricably tied to conventional agricultural production through the use of inorganic fertilizers. The U.S. General Accountability Office (GAO) reported in 2003 that the cost of natural gas accounted for up to 90 percent of the cost of nitrogen fertilizer in the United States. Decreased domestic natural gas supplies resulted in decreased domestic nitrogen fertilizer production and lower crop yields as recently as 2001.[22] Natural gas prices spiked again in 2005, and testimony to the United States Senate Committee on Energy and Natural Resources stated that "almost one-third of U.S. crop production is derived from nitrogen fertilizer" and over 93 percent of the total cash cost of production of nitrogen fertilizer is from the cost of natural gas.[23]

The U.S. imports most of the nitrogen fertilizer it uses. Worldwide, fertilizer production consumes approximately 1.2 percent of the world's energy and is responsible for about 1.2 percent of the total emission of the greenhouse gases.[24] Additionally, nitrogen fertilization of soils accounted for 9 percent of U.S. industrial greenhouse gas emissions in 2005 (60 percent of total nitrous oxide emissions).[25] Fertilizers can also cause environmental damage when they leach from soils, contributing to eutrophication (the nutrient-loading of waterbodies). Eutrophication resulting from agricultural runoff is, along with soil erosion, one of the leading causes of water impairment in the United States.[26]

The contribution of petroleum products to carbon dioxide emissions has become a topic of considerable policy attention recently, helping to renew interest in plant-derived industrial feedstocks. Industrial hemp products help to mitigate elevated atmospheric carbon dioxide levels through carbon sequestration.

Wood-based paper manufacturing, which has replaced the use of agricultural fibers like hemp for papermaking, is the fourth most energy-intensive industry in the United States today, accounting for 5.6 percent of industrial carbon dioxide emissions in 2005.[27] Paper manufacturing from wood pulp also typically requires the use of sulphur and chlorine, chemicals known to cause environmental harm. The high chemical and energy requirements of wood pulping result from the need to remove the lignin content (a type of plant glue) and isolate the useful cellulose present in the raw material. The balance of cellulose to lignin is more favorable in fiber crops, and hemp is a prime example.

The legal status of hemp particularly impedes its use in emerging technologies, such as composite construction materials. Concrete and fiberglass, used for their strength and insulating properties in construction, both require large amounts of energy for their manufacture. The production of nonmetallic mineral products (including cement, glass and lime) is the smallest subgroup of carbon dioxide emissions from manufacturing in the United States today, but cement and lime production are by far the most carbon-intensive manufacturing types in terms of CO_2 produced per BTU used, and contribute 2.8 and 0.7 percent of emissions, respectively.[28] Research is currently underway in Britain to determine whether industrial hemp-based building alternatives to concrete and lime can be used to construct "carbon-neutral" energy-efficient houses.[29] Composite materials can also deliver considerable fuel energy savings when used to replace heavier mineral composites in transportation, such as automobile interiors. Greater exploitation of industrial hemp in these kinds of construction materials in the United States is limited, perhaps to a greater degree than the applications discussed above, by the lack of a domestic hemp fiber supply.

Finally, U.S. policy not only prohibits experimentation with industrial hemp, it directly subsidizes the production of competing commodities that might be environmentally inferior. High-yield hemp crops are often said to grow best in the same areas that produce corn and wheat. In 1995, the USDA also investigated hemp as an alternative for tobacco farming.[30] The Environmental Working Group reports that, from 1995 to 2005, U.S. direct agricultural subsidy programs amounted to $51.3 billion for corn, $21.0 billion for wheat, and $530 million for tobacco.

Cotton, a fiber comparable in many ways to hemp, was the third-highest subsidized crop in the period at $15.8 billion.[31] Timber and petroleum also benefit from implicit subsidies through U.S. Forest Service timber extraction and foreign policy programs, respectively.

Fuels derived from crops in the United States are eligible for additional government support in the form of tax breaks and tariffs, as well as state and federal grants and loans for infrastructure development. According to the American Enterprise Institute, “the single largest energy tax expenditure in the U.S. budget is the tax credit for alcohol fuels, with a five-year revenue cost of $12.7 billion,” primarily benefiting corn-based ethanol.[32] Canola and soybeans, other competitors in the biofuel market, are also subsidized. In 2007 alone, the U.S. Department of Energy announced $585 million in grants to roughly one dozen companies working to produce cellulosic ethanol.[33]

The balance of prime croplands used for food, fiber, and biomass production should be viewed in the context of the massive agricultural subsidy programs in the United States and abroad that interfere with optimal levels and locations of agricultural production.

Part 4

Crop Inputs and Requirements

Countless varieties of industrial hemp have been bred by farmers around the world. Seedstock developed in the early history of the United States appears to have been lost during the extended period of hemp prohibition. In Europe and Canada, certified seed programs have developed patented low-tetrahydrocannabinol (low-THC) varietals, and research continues to breed varieties maximized for specific qualities: cellulose for biofuels, fiber yield for textiles, proteins for food, and so on.

Industrial hemp is typically planted in April or May, with harvest of the fiber crop in an average of 90 days. If grown for seed, the crop takes approximately 30 to 45 additional days to mature. This relatively short time between seeding and harvest opens up a large number of possibilities for complimentary crop rotation, especially in an area like California, where hemp could be planted as early as February. Hawaiian hemp advocates boast of a local climate capable of producing "at least" three hemp crops per year.[34] The relationship between industrial hemp crops and other crops grown in rotation is an important economic and agronomic consideration.

Significant in hemp's credentials as a low-impact industrial feedstock are the medium-to-low inputs required for growing the crop. Herbicides are not typically required in hemp cultivation, since, when grown for fiber, industrial hemp crops are seeded at very high densities, and the plants' rapid growth crowds out most weed species that might be present in the field. (Hemp seed crops, which are grown with more space between plants, do not perform as well in this regard.) Industrial hemp is also grown profitably with little or no use of pesticides. In Canada and Europe, damage caused by insect pests and disease is usually negligible. It is fair to assume that industrial hemp grown intensively (with fertilizer and irrigation) in monoculture over time would eventually develop pests and disease that required treatment. If generalizations from experience with other crops hold true with hemp, the prevalence of harmful pests could be minimized through boosting genetic diversity and crop rotation.

Reported fertilizer use for hemp range widely. At the high end, fertilizer requirements are similar to those of corn or a high-yielding wheat crop. Nitrogen is principal in feeding and sustaining the rapid biomass growth of these crops. In Canada, industrial hemp is reportedly being grown with anywhere from 55 to 80 pounds per acre nitrogen and 30 to 40 pounds per acre phosphate.[35] Much higher nitrogen fertilizer rates are often reported (80 to 110 pounds per acre) and 52 to 70 pounds per acre potash is recommended.[36] Farmers may minimize the need for inorganic nitrogen through applying organic mulch or growing the hemp in rotation with a nitrogen-enriching crop. On average, industrial hemp grown for fiber has lower nitrogen needs than seed crops.

Hemp is drought-tolerant once established, but reliably high yields for either the seed or fiber crop are associated with supplemental irrigation. Hemp requires 10 to 14 inches of rainfall or irrigation during the first six weeks of growth, and that much again throughout the growing season. Irrigation needs are less than those of many of the competing crops.

The broad adaptability of hemp to different climates makes it a viable crop on virtually all the nation's cropland. In practice, however, it has been grown in states where summer rains or abundant irrigation is available: Kentucky, Wisconsin, California, North Dakota, South Dakota, Minnesota, Indiana, Illinois, Ohio, Michigan, Kansas, and Iowa. Wild *Cannabis sativa*, a relict of historic hemp crops, grows so prolifically in parts of the country that 98 percent of the plants seized every year through the Drug Enforcement Administration's Domestic Cannabis Eradication/Suppression Program are this feral "ditchweed" rather than cultivated marijuana.[37]

One rigorous life-cycle analysis has been conducted on field production of fiber hemp.[38] This study compared emissions and resource use per acre for all the processes up to and including harvest of industrial hemp as compared to seven other major crops in France: sunflower, canola/rapeseed, pea, wheat, maize/corn, potato, and sugar beet. In impact categories—which included eutrophication, climate change, acidification, terrestrial ecotoxicity, and energy use—fiber hemp and sunflower were found to have consistently low impacts and potato and sugar beet were found to have consistently high environmental impacts. In this and other studies, reduction of eutrophication resulting from leaching of nitrogen fertilizers was identified as a priority for improving environmental effects of industrial hemp cultivation.

Table 1: Comparison of Agricultural Inputs For Hemp And Other Common Crops, in Pounds per acre

	Hemp	Rape seed	Wheat	Maize (Corn)	Sugar beet
Nitrogen (ammonium nitrate)	67	98	116	89	196
P2O5 (triple superphosphate)	34	37	57	46	90
K2O (potassium chloride)	101	27	80	27	161
Pesticide (active ingredient)	0.0	2.6	2.6	3.1	3.3

Exerpted from a "good agricultural practice production scenario" for hemp and other major arable crops produced in France, in Hayo M. G. van der Werf, "Life Cycle Analysis of field production of fibre hemp, the effect of production practices on environmental impacts," *Euphytica* (2004), pp. 13–23.

Part 5

Yield and Qualities as an Industrial Crop

Any honest claims about production of industrial hemp in the United States must be prefaced by the fact that meaningful current yield data is unavailable for this country. The cost imposed by federal regulation on any potential field trial has made it virtually impossible to collect useful data. Wild estimates of the productivity of hemp as a crop have gone so far as to claim that "hemp is the number one biomass producer on planet earth: 10 tons per acre in approximately four months."[39]

A more realistic estimate of industrial hemp productivity in the United States, at least initially, seems to be in the range of two to five tons of dry stems per acre—less than any number of common crops, including corn and sugar cane, or specialty crops like kenaf. *Arundo donax*, or giant reed, a type of grass invading western states, can grow two feet a week for a period of months, reaching biomass of more than 30 tons per acre.

Biomass is perhaps the least important measure of hemp yield, however. The composition of the hemp stalk—averaging around 25 to 35 percent bast fiber—determines how much of the plant is useful in specific applications. Yield is also a factor of processing, which includes technological innovation at every stage: cutting the plant in the field, retting, baling, pulping, and so on. In paper production, usable pulp yield per acre (a factor of both cellulose content and processing technology) is a more meaningful measure than biomass or raw fiber yield. Fiber length, cellulose content, and lignin content are three quality parameters important to most industrial uses.

If the fiber is stripped from the stalk, 65 to 75 percent of the biomass remains as woody "hurds." This core material is comprised of short fibers, lower in cellulose and higher in lignin, giving it industrial qualities more similar to wood or cereal straw than to cotton.

There is still potential for improving hemp through selective plant breeding and genetic engineering, developing different varieties for each intended market.

Aggressive crop research and development might help growers in the United States to realize a crop yield in the range of six to eight tons of dry stems per acre, approaching the reported yields of specialized hemp varietals grown historically in the United States or in ideal conditions in other parts of the world. (To this end, hemp experts in the United States believe that the genetic stock of wild “ditchweed” would be valuable for breeding regionally specialized hemp varietals domestically in the future.) Maximization of fiber production of the hemp plant through plant breeding and growing conditions typically reduces or eliminates the potential for seed production, and vice versa, but some breeding programs aim to grow hemp plants with a favorable balance of both products.

Table 2: Estimated Chemical and Physical Qualities of U.S. Fiber and Biomass Crops

	Cellulose (percent)[a]	Lignin (percent)[a]	Fiber length, avg. (mm)	Fiber diameter, avg. (microns)	Biomass (dry ton/acre)	Seed (lbs/ acre)	Seed oil content (percent)	Average Oil Yield (gal/ acre)[b]
Hemp (bark/bast)	55–65	2–4	25.0	22	2–5, potential for 6–7	450–1800, potential for 2500	31–33	37
Hemp (core/hurd)	39–49	16–23	0.5	31				
Hemp (whole stalk)	43–51	9–13	-	-				
Kenaf (bast)	31–39	15–18	2.7	20	6–8, potential for 9–10	-	-	28
Kenaf (core)	34	17.5	0.6	30				
Flax tow (oilseed variety)	34	23	27.0	22	-	1500–2500	40	49
Flax tow (textile variety)	50–68	10–15	28.0	21	-	-	-	-
Cotton (staple)	85–90	3–3.3	30.0	20	-	1000	13	33
Cotton (linters)	80–85	3–3.5	3.5	21				
Canola/rapeseed	-	-	-	-	1–2	2000–4000	40–45	122
Rice	28–36	12–16	1.4	8	-	6600	-	85
Oats	31–37	16–19	1.4	15	-	3600	-	22
Corn	28–35	16–21	1.3	16	4	7800	-	18
Giant reed	29–33	21	1.2	15	8–10	-	-	-
Switchgrass	32–43	34–36	1.4	13	5 or more	-	-	-
Coniferous trees (softwood)	40–45	26–34	3.0	30	1–2 forest, 2–5 plantation	-	-	-
Deciduous trees (hardwood)	38–49	23–30	1.3	25	4–7	-	-	-

From [a]HurterConsult, Inc. www.hurterconsult.com/nonwood_characteristics.htm; [b]Joshua Tickell, “From the Fryer to the Fuel Tank: The Complete Guide to Using Vegetable Oil as an Alternative Fuel” in Al Kurki et al., *Biodiesel: The Sustainability Dimensions*, National Sustainable Agriculture Information Service, 2006; and various other sources.

Part 6

Industrial Applications

Before the development and invention of wood-pulping processes in Germany in the 1840s, hemp and cotton rags were important pulp sources for papermaking. Before the invention of the cotton gin, hemp was often a preferred fiber source for clothing. In both cases, it was the labor-saving mechanization of production, not necessarily the inherent inadequacy of hemp as a raw material, that drove its replacement. Some of the industrial applications of hemp as a raw material today propose to renew these historic uses with updated technologies. In other sectors, hemp is being developed as an industrial feedstock to address distinctly modern issues: biofuels as an alternative to petroleum fuels, and energy-efficient composite building materials.

A. Paper

Three qualities of hemp make it an attractive raw material for papermaking: hemp fibers are long (lending strength to paper) and hemp contains high levels of cellulose (corresponding with high pulp yield from the raw stalk) and low lignin content (an undesirable constituent that requires intensive processing to remove). But while hemp as a raw material has clear environmental advantages, both growing and processing hemp pose challenges that detract from its environmental bottom line.

As discussed earlier, wood-based papermaking is one of the top industrial consumers of energy in the United States. Trees contain both high levels of cellulose and high levels of lignin, an organic polymer that helps give them their woody character. The bast fibers of specialized industrial hemp cultivars can contain as much as 77 percent cellulose and as little as 3 percent lignin, compared to 45 and 25 percent, respectively, in wood. As a result, hemp requires 70 to 80 percent of the energy required to pulp wood fibers.[40]

The paper industry employs a number of different processes to make different kinds of pulp that vary substantially in the temperatures, mechanical procedures, and chemicals used, as well as the yield and quality of the paper output. Because of both its chemical and physical composition, hemp can produce high pulp yields and can be pulped without use of the *Kraft* process (used for chemical pulping of wood and long-fiber specialty papers) which uses sulfur compounds that are environmentally toxic. Also, as with other non-wood pulp, hemp can be bleached with peroxide and through other processes that do not involve chlorine. The environmentally preferable pulping processes are those, such as the Organosolv process, where processing chemicals and waste products can be recovered and reused either within the pulping mill or as marketable byproducts like fuel or fertilizer.

Pulping hemp requires less energy and potentially creates less chemical waste than wood pulping; in some instances, however, this could be a tradeoff rather than a net gain. The wood pulp industry partially compensates for the energy required for pulping by generating a proportion of its energy needs from waste wood scraps and spent chemicals. As a result, the industry is considered more carbon-neutral than some comparable manufacturing groups. Additionally, the larger mills used for processing wood into pulp generally have a better economy of scale when it comes to capturing and reprocessing the chemicals used in the pulping process than do smaller hemp pulping mills. The relative potential of wood versus hemp pulping for closed-loop or “zero-waste” manufacturing hasn’t been tested on a large scale.

The advantages of hemp over wood in the pulping stage are generally accepted, but it isn’t the cost of wood pulp that has driven most of the interest in hemp for papermaking in the United States and Europe—it is the cost of food crops. Both the USDA’s 1950s and ’60s search for new fiber crops and the research on hemp papermaking initiated in the 1980s in the Netherlands, for example, were motivated primarily by interest in diversifying national agriculture to include a better balance of food crops (which were often in surplus) and non-food crops.

There is a good reason why, where available, trees are often a more efficient source of pulp than non-wood fiber crops. The advantages of non-wood fiber crops, such as lower energy requirements for pulping, decreased production time, and increased yield, come with a cost: production of annual crops requires more irrigation, pesticides, and fertilizers than tree forests or plantations, and results in frequent disturbance associated with annual planting and harvest, lower incidental wildlife and other ecological value, and higher transportation and storage costs. A tree plantation grown over a number of years may require some irrigation and fertilizer initially, but active management is minimal for the subsequent years until harvest. Hemp crops are irrigated and fertilized every year, with farm equipment making dozens if not hundreds of passes over the field in the time that equivalent plantation trees take to grow. The yield of industrial hemp and U.S. tree plantations on a per acre basis appears to be in the same general range, depending on pulping processes used.

Because hemp has a number of qualities that make it superior to wood for the production of paper, the pulping is more efficient both environmentally and economically, but an investment has already occurred (in terms of fuel energy, chemical inputs, etc.) before that point. Often, some of the “benefits” of hemp fiber for paper are irrelevant. For instance, it doesn’t matter if a crop grows more biomass faster unless land is in short supply; it doesn’t matter how strong hemp fiber is unless stronger paper is required.

Geographic variation in costs is very important in assessing both environmental considerations involved in life-cycle assessment of wood and hemp paper production and determining real-world feasibility. Industrial hemp production for paper is likely far preferable to logging intact temperate or tropical rainforests, but such analysis is outside the scope of the present study. Hemp is used extensively in France and other European countries for papermaking, even by U.S. paper companies based overseas.[41] Wheat straw, sugarcane bagasse, and other agricultural crop residues are used to make paper in other parts of the world. Straw left in the field after grain harvest in the United States is a waste problem that has motivated interest in the use of agricultural byproducts for papermaking for more than a century, but without much result. Trends toward both greater wood products and food demand and equal- or lower-intensity management of forests and agricultural lands, as well as less-polluting manufacturing processes, suggest that diverse paper sources will always be needed.

Case 1: Hemp vs. Tree Pulp Production for Paper in Minnesota, Wisconsin

The USDA "Search for New Fiber Crops" in the 1950s and Environmental Defense's "Paper Task Force" report in 1996 reached the same conclusion: the new crop with the biggest potential is kenaf. That conclusion didn't do much good for farmers in the northern United States, where kenaf, a tropical *Hibiscus*, won't grow. Similarly, the highly productive tree plantations found in the southern states don't grow in Wisconsin. However, the Great Lakes region has long had one of the greatest concentrations of paper and pulp mills in the nation. Although timber production for paper pulp is increasingly shifting to other countries, mills in the United States still account for roughly one-third of world pulp production.

In his evaluation of environmental impacts of industrial hemp for papermaking in Minnesota, Bowyer (2001) expressed concern that the fiber supply in Minnesota is increasingly limiting its paper production industry, but concluded, "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." Though the report acknowledged that process energy would be less for hemp than for wood, it did not address less-toxic pulping processes available for hemp papermaking.[42]

Mills on Wisconsin's Fox River deal mainly in de-inking and recycling paper waste imported from out of the state, a resource-intensive process that results in high volumes of dioxin and other toxic chlorine compounds, both from the original pulping and in the re-bleaching of the material for use in new paper. Though environmental operating conditions of U.S. wood-based pulp and paper mills continue to improve, inclusion of a greater percentage of agricultural residue and fiber crops like hemp in the paper stream would make both ecological and economic sense in some regions. Individual pulp mills could add on a non-wood pulping line to supplement production when wood is scarce without substantially changing the quality of the paper; for instance, mixing 20 to 30 percent hemp pulp into the tree pulp, as market conditions dictated, or supplementing recycled wood paper pulp with hemp fiber. A 1997 USDA Forest Products Laboratory market analysis optimistically concluded that Wisconsin farmers could profitably produce hemp to meet the paper fiber demands of the state.[43]

In the United States, much of the future demand for paper will be met with increased plantation forests and paper recycling, but it is possible that agricultural crop residues and non-wood pulp crops might also play a role at some time. Hemp fiber could be a tool for that at a later date—the long fibers could add strength to recycled paper pulps, it could be grown as a paper crop, or it could be grown for a higher-valued market, with residual material supplementing wood pulp at paper mills. Cost-reducing technological improvements in the harvest, transport, and processing of hemp, as well as environmental considerations, would be key factors. Currently, industrial hemp is most competitive as a pulp source in small niche paper markets where the qualities of hemp paper pulps—high tear and wet strength, stiffness and bulk—have unique value, including cigarette papers, filter papers, tea bags, currency, and other specialty papers (markets shared by other non-wood fibers like cotton, abaca, and flax). Economic analyses suggest that other markets where hemp has potential are in unbleached cardboard packaging and transport materials. Environmentally, however, little net benefit could be expected from the substitution of hemp papermaking for domestic tree plantations and modern wood pulp mills.

B. Cloth

Cotton is the dominant natural fiber used in textiles worldwide today. It accounts for about 40 percent of textile production, while synthetic fibers (primarily polyester) account for approximately 55 percent of textile production.[44] One study of hemp for the U.S. market suggests that, "an area of land only 25 miles square (the size of a typical U.S. county) is sufficient to produce enough hemp fiber in one year to manufacture 100 million pair of denim jeans, thus providing an equivalent yield to an area ten times the size planted in cotton, and offering the additional benefit of producing clothing which is 10 times stronger than cotton and that, in contrast to cotton which requires exceptionally high applications of pesticides and enormous quantities of water, requires no pesticides and only minimal quantities of water as well."[45] In fact, cotton inputs and yields show very large variation throughout the world as well as within the cotton-producing areas of the United States. Based on the best available estimates for domestic cotton and hemp production, the degree of industrial hemp efficiency over cotton appears to be somewhat exaggerated in popular references on the topic, in part due to incomplete life-cycle analyses of each fiber.

The United States grows an average of 14 million acres of cotton each year, with lint (fiber) yield for the past 10 years averaging a little more than 700 pounds per acre.[46] (Cotton fiber, derived from the flower of the plant rather than the stalk as in hemp, is a little more than one-third of the raw cotton yield, after the seed is removed.) By comparison, industrial hemp fiber production for high quality paper markets in France yields a dry-stem average of 3.1 tons per acre, of which 34 to 39 percent (an average of 2300 pounds per acre) is long fiber suitable for cotton-type textiles.[47] Industrial hemp-fiber yield appears to be roughly three times per acre that of domestic cotton—not 10 times—although, cotton crops take twice as long to mature (180 days instead of 90).

Industrial hemp is a famously durable fiber well-suited to jeans. A few U.S. companies make jeans from hemp, mostly of Chinese origin, or hemp-cotton and hemp-polyester blends. Fiber blends are used both to improve the feel of the fabric (hemp fiber manufacturing currently produces a cloth that is a bit coarser than cotton) and to reduce the cost of the materials (hemp is more expensive, particularly when imported into the United States). Retailers' claims about the durability of hemp jeans range from two to 26-times stronger than cotton. Because different fiber processing techniques and fabric weights and weaves result in different strengths, a range is to be expected. Two companies that manufacture hemp jeans reportedly found that, overall, the hemp fabric had 62 percent greater tear strength and 102 percent greater tensile strength than a comparable cotton product in one case, and eight times the tensile strength and four times the durability of other natural fibers in the other case. [48]

With the exception of a small amount of organic cotton production, virtually all of the cotton in the United States is treated multiple times a year with herbicide, while most of it also receives treatments of insecticide, fungicide, and chemical defoliants. In 2003, total pesticide treatment rates ranged from four to 19 pounds of active ingredient per treated acre, depending on the region.[49] The yearly national average appears to be in the lower end of that range. As discussed earlier, industrial hemp is typically grown with few or no pesticides. Irrigation and fertilizer inputs differ too much between cotton-producing regions in the United States to make a meaningful general comparison to hemp farming practices.

Cherret et al. (2005) attempted to compare the amounts of water and energy required for organic and conventionally grown hemp and cotton as well as polyester, by looking at each process involved in producing the fiber, from the sowing of the seed (or extraction of the mineral oil in the case of polyester) through to the spinning of the thread, but found that the data required for such analysis wasn't readily available.[50] However, polyester manufacturing was found to require six times the total energy (36 percent of it for chemical feedstock) compared to U.S. cotton production or hemp production per ton in the case studies examined. The chief difference between energy requirements in industrial hemp and cotton production was that most of the cotton energy requirement was a result of pesticide and irrigation, while most of the hemp energy consumption was due to the intensive processing necessary to generate the fiber.

Clearly, cotton, hemp, and polyester all perform differently during use, and the environmental costs of production need to be examined within the context of the full life cycle of textile products in each category. Looking only at environmental costs of production, however, an ideal textile fiber of the future might have the water requirements of polyester, the agricultural inputs of hemp, and the processing energy of cotton. Additionally, advances in industrial cellulose fiber production, such as Viscose and Tencel, and region-specific considerations will continue to contribute to the environmental impact of each fiber.

Case 2: Hemp vs. Cotton Crop Production in California

Cotton is a crop especially suited to warm or hot climates, but it also requires relatively high quantities of available nutrients and water. California and the desert southwest meet these requirements, due in large part to the massive state- and federally built irrigation projects in these areas. All cotton grown in California is irrigated.

Nitrogen is the primary nutrient applied to cotton throughout the growing season. A pre-emergent herbicide is incorporated into the soil in the fall, followed by an "over-the-top" application of herbicide before planting the cotton in the spring. The cotton crop typically requires one or more applications of herbicide and pesticide during the growing season, followed by the application of chemical defoliants before harvest. Cotton farmers also use chemical growth regulators, sprayed on the crop in the middle of the summer, to promote the even maturation of the crop. Transgenic varieties of cotton, engineered for herbicide tolerance and, in some cases, pest resistance, were not found to substantially change crop inputs or yields in the California cost studies reviewed here. (In the Imperial Valley cost study, the variety used is transgenic, engineered with Bt toxin for pink bollworm control and tolerance of Roundup brand herbicide.)

Accounting only for the active ingredients, almost seven million pounds—or 4 percent—of the pesticides used in California in 2005 were applied to cotton. The rate of application was much lower than the national average, at 0.6 pounds per acre treated.[51] Chemical defoliants topped the list of chemicals used by weight, followed by growth regulators, insecticides and herbicides.[52] In addition to being a significant cost of production in terms of energy, agricultural chemicals can pose a serious environmental health risk, particularly to agricultural workers, certain wildlife species (beyond those targeted by the pesticide), and through accidental spills. (One of the worst pesticide accidents in history was the 1991 metam-sodium spill resulting from a train derailment which temporarily sterilized a 38-mile stretch of the Sacramento River. This pesticide is still used in the production of cotton and other California crops today.)

Selenium-laden runoff as a result of over-irrigation is also a threat to wildlife, most notably implicated in large numbers of bird and other wildlife deaths at the Kesterson National Wildlife Refuge in the early 1980s. Irrigation runoff also carries sediment, pesticides, fertilizer, and other contaminants, contributing to eutrophication and toxicity in nearby waterways.

The fiber from cotton, called "lint," comes from the flower rather than the stalk of the plant, as in hemp. Two commercial products are derived from the harvested cotton flower, the seed and the lint, but, in the cases represented here, the cotton grower typically sells only the lint. (The seed is given to the cotton ginner in exchange for the ginning service.)

Cotton grown in California demands a price high enough to partially offset the above-average production costs. The costs of production have also historically been offset by three major price-support programs for Upland cotton under the Farm Security and Rural Investment Act of 2002 (Pima cotton is not eligible) and other government supports, including crop-loss payments, loans, and insurance. Nationwide, a Congressional Research Service report found that, from 1991 to 2003, U.S. farm cotton revenues annually averaged \$0.57/lb from the marketplace plus farm subsidy payments of \$0.21/lb. (\$1.4 billion in subsidies annually).[53] Total revenues as well as total economic costs averaged \$0.78/lb. The report concludes, "In the absence of support programs, the data suggest a sizeable proportion of cotton would not be profitable." In California, direct federal subsidies for cotton amounted to \$2.2 billion between 1995 and 2005.[54] On top of that, the subsidized value of water from the Central Valley Project is likely in the hundreds of millions of dollars annually.[55]

Comparing average cotton production costs for California's three cotton-growing regions (Sacramento Valley, San Joaquin Valley, and Imperial Valley), and three cotton varietals (Acala, Upland and Pima), to conservative estimates of irrigation, fertilizer, and pesticide use for fiber hemp production suggests that, acre-for-acre and pound-for-pound, the substitution of industrial hemp for cotton in the state would reduce harms to the environment. The greatest benefit would likely be in reduced nitrogen fertilizer use, followed by reduced irrigation use—production of industrial hemp would require less than half the inputs needed for cotton cultivation in the Imperial Valley. Though potentially planted at the same time of year as cotton, hemp could also mature in half as much as cotton.

Table 3: Environmental Efficiency of Cotton Production in California Compared to Industrial Hemp

	Irrigation	Nitrogen per acre	Pesticide and other chemical treatments	Days to harvest	Yield
Sacramento Valley Upland cotton [a]	36 acre inches	150 lbs.	9 applications	Approx. 180	1,250 lbs. lint (2,300 lbs seed)
San Joaquin Valley Acala cotton [b]	30 acre inches	181 lbs.	9 applications		1,250 lbs. lint (2,222 lbs. seed)
San Joaquin Valley Pima cotton [c]	30 acre inches	180 lbs.	9 applications		1,150 lbs. lint (2,067 lbs. seed)
Imperial Valley [d]	60 acre inches	250 lbs. (plus 104 lbs. phosphorus)	9 applications	170 to 200+	1,500 lbs. lint
Industrial hemp	28 acre inches	55–110 lbs. (plus 35 lbs. phosphorus)	little or none, at least initially	90	1,400 to 3,500 lbs. bast fiber (does not include hurd or seed)
Relative environmental efficiency of hemp crop	+7 to 53%	+27 to 78%	positive	+47 to 55%	-7 to +204%

From [a] Douglas J. Munier et al., *Sample Costs to Produce California Upland Cotton: Sacramento Valley 2002,* University of California Cooperative Extension; [b] Robert B. Hutmacher et al., *Sample Costs to Produce Cotton–Acala Variety*, *40 in. rows: San Joaquin Valley 2003*, University of California Cooperative Extension; [c] Robert B. Hutmacher et al., *Sample Costs to Produce Cotton–Pima Variety: San Joaquin Valley 2003*, University of California Cooperative Extension; [d] Herman S. Meister, *Sample Cost to Establish and Produce Cotton: Imperial County 2004*, University of California Cooperative Extension; [e] Estimated at 2 to 5 tons/acre (4,000 to 10,000 pounds per acre), 35 percent fiber yield.

C. Fuel

Prompted by public clamor over foreign oil imports and greenhouse gas emissions, this year the federal government announced the establishment of a comprehensive Renewable Fuel Standard Program and plans to reduce projected increases in U.S. gasoline consumption by 20 percent in the next decade. Though the fuel best poised to benefit from these new policy mandates is corn ethanol, numerous alternatives exist, including industrial hemp as a feedstock for various biofuels.

The feedstocks most prominently considered for biofuel production in the United States have been subsidized crops like corn, soy, and canola. Unfortunately—given the various mandates in place meant to boost production and consumption of corn ethanol—using conventional farming methods and current processing technology to make grain ethanol from corn can consume more fossil-fuel energy (mostly coal and natural gas) than the ethanol fuel it produces.[56] The potential for carbon-neutral ethanol production is still a topic of intense research and debate. At the optimistic end of the debate, life-cycle assessments have suggested that cellulosic ethanol could reduce greenhouse gas emissions by more than 80 percent below of those of gasoline, as compared to a 20 or 40 percent reduction in emissions (at best) derived from corn-based grain ethanol.[57] (This is in large part due to the fact that, as in the paper pulping process, waste material in the cellulosic ethanol process can be gasified for energy to power the mill facilities.)

Of course, many factors in the environmental cost-benefit analysis of producing fuel from an agricultural crop rather than petrochemical feedstocks are similar to those discussed in the earlier comparison of dedicated fiber crops versus wood or agricultural residues for paper production. (In the comparison of hemp to tree crops for cellulosic ethanol production, the analysis is nearly parallel—including the higher transportation costs of low-density hemp compared to wood crops.) The life-cycle assessment of ethanol also depends on the balance between hydrocarbon inputs (such as fertilizer and fuel energy needed for farming, transporting, and processing the crop) and both crop and ethanol yield. The hypothetical carbon-neutrality of biofuel use depends on the unlikely event of hydrocarbons being eliminated from the production process. However, industrial hemp outperforms corn on several counts: slightly higher soil conservation depending on tillage and other culture, lower herbicide and insecticide requirements, higher potential biomass/cellulose yield, and greater suitability for cellulosic rather than grain ethanol production. (Perennial trees or grasses, produced without tillage or synthetic pesticide and fertilizer inputs, could represent greater environmental performance gains over corn than hemp—the only advantage of hemp in that case would be greater ease of rotation with other annual crops.)

A widely published claim is that hemp cultivated on just 6 percent in the United States could supply all of our oil and gas needs.[58] The reference for this estimate was a 1984 textbook which stated: "Meeting US demands for oil and gas would require that about 6% of the land area of the coterminous 48 states be cultivated intensively for energy production."[59] Hemp was not specifically evaluated for this statement and, clearly, even if the claim were true, 6 percent of U.S. continental landmass (the equivalent of approximately 27 percent of the nation's agricultural land) is an unrealistically large amount of land to dedicate to any single energy crop.

A more recent report from the U.S. Departments of Agriculture and Energy makes a less ambitious claim: one billion dry tons of biomass could supply the equivalent of 30 percent of the nation's annual petroleum consumption for transportation.[60] At an average of 3.5 tons per acre, industrial hemp would require the equivalent of almost two-thirds of the nation's conventional cropland to meet those estimates.

Nevertheless, production of ethanol from biomass rests on technologies that unlock the cellulose content of crops, and in this regard hemp is still a candidate (see Table 2). The California Energy Commission is among those agencies that have listed hemp as a potential biomass energy crop.[61]

Research into the cost-effective production of cellulosic ethanol is in progress, with commercial breakthroughs still some years away. A biofuel more readily produced from hemp is biodiesel. A recent study evaluated industrial hemp along with seven other seed crops for biodiesel production in Oregon.[62] Hemp ranked in the middle of the group for yield in the study, with canola the preferred seed crop. An exceptional seed yield, such as the record 3000 pounds of hemp seed per acre reported in one Canadian crop in 2005, would be necessary to make the crop yield competitive with canola on a gallons-per-acre basis.[63] The Oregon study assumed a more average yield of 600 to 1,000 pounds per acre, and noted that in Oregon, supplemental irrigation and "severe legislative restrictions" would make hemp an expensive source of biodiesel. A Spanish study in 2005 comparing hemp-derived biodiesel and petroleum diesel came to more favorable conclusions: assuming an oil yield between 17 and 85 gallons per acre, the analysis reported that energy consumption and net carbon dioxide emissions for the life cycle of hemp biodiesel were a small fraction of the equivalent functional unit of diesel fuel, and that eutrophication potential due to the use of chemical fertilizers was industrial hemp's single major comparative shortcoming.[64]

It is unlikely that industrial hemp would be a primary crop for either biodiesel or ethanol production where more valuable markets exist for hemp, and more specialized oil and biomass crops like canola, perennial grasses, and trees are available. At most, given current technology, biomass could be expected to serve as a secondary market for fiber hemp (as is sometimes the case in Europe) or as a local fuel source, whether in the form of biodiesel, pellets for heating, or other emerging fuels.

D. Composites

Though use of natural fibers in composite materials is a relatively new market for hemp, it is already a well-proven one. Hemp composites perform well in many applications requiring moisture adsorption and desorption, thermal and acoustic insulation, stiffness, and strength. Industrial hemp composites are found in automotive and general construction materials, geotextiles, filters, and other applications, many of which replace materials with greater environmental costs. Natural fiber benefits over mineral fibers include better occupational safety conditions, lower manufacturing costs (including equipment wear and energy consumption), greater recyclability (especially within the manufacturing process), and favorable weight and strength characteristics (especially their high stiffness with low weight per volume), and more economic product end-of-life options.

In particular, the use of industrial hemp in natural fiber-reinforced plastics (thermosets and thermoplastics) has grown from virtually nonexistent a decade ago, to widespread use today by BMW, Ford, Daimler, General Motors, Honda, Mitsubishi, Porsche, Volkswagen, and other vehicle makers. Automotive hemp composites include interior lining, insulation, and, increasingly, structural panels. Natural fiber suppliers have reported growth of 10 to 15 percent per year in the automobile market since 2000.[65] This growth is largely due to increased natural fiber replacement of less versatile wood fiberboard and, more recently, fiberglass-reinforced components, the latter spurred by post-consumer product recycling mandates in Europe and Japan. (In the United States, the Federal Biobased Products Preferred Procurement Program is another potentially important regulatory driver for bio-composites.) In the past, glass and asbestos fibers have been the most common mineral fibers and flax and jute have been the most common vegetable fibers used in automotive composites. Today, hemp and kenaf fibers are recognized as superior fibers for bio-composite applications, but they must compete with cheaper fibers, including agricultural waste products.

Mats blended from 50 percent or more natural fibers (jute, kenaf, flax, or hemp) in a matrix of polypropylene or polyester are typical of bio-composites manufactured for the automotive industry in the United States and Europe today.[66] Natural fiber blends are used both to optimize performance, by taking advantage of the different qualities of each fiber, and to ensure relatively consistent product performance, since availability and quality of each fiber crop can be unreliable. Hemp would be used in greater quantities if supplies were dependable and cost-competitive, especially domestically. The bio-composite industry anticipates growth from development of manufacturing techniques aimed at reducing moisture absorption by natural fibers, and improved breeding and cultivation of fiber sources like industrial hemp to bring standard conformity of the fibers closer to that of mineral fibers, two of the major areas limiting product performance of bio-composites. Another significant technological development is manufacture of entirely bio-based composites through the substitution of petroleum polymer matrices with cellulosic plant-based plastics (e.g., resins developed from soy beans).[67]

Since hemp and other natural fibers are usually used in a matrix of polypropylene (or another synthetic polymer) in these composites, net savings in manufacturing energy result both from the glass replaced as well as the greater proportion of natural fiber used in the matrix material. Energy use in glass fiber appears to be in the range of five times the energy required for hemp fiber production—polypropylene, ABS (acrylonitrile-butadiene-styrene), and epoxy resin require at least 10 to 20 times as much energy for the same weight, respectively.[68] The lower energy requirements also result in reduced carbon dioxide emissions during manufacturing. Ford engineers reported that hemp-reinforced polypropylene components in the Mondeo sedan resulted in 31 percent less CO_2 emissions than the equivalent glass-fiber reinforced components.[69]

Table 4: Assessment of Energy Requirements and Select Emissions for Manufacturing of a Side Panel for the Audi A3 Car Made from ABS Co-Polymer vs. an Alternative Design Made from 66 Percent Hemp Fiber (by volume) and Epoxy Resin Composite Matrix			Relative environmental efficiency of hemp component
	ABS copolymer	Hemp-epoxy composite	
Total energy (MJ)	132.00	73.00	+45%
CO_2 emissions (kg)	4.97	4.19	+16%
Methane (g)	17.43	16.96	+3%
SO_2 emissions (g)	17.54	10.70	+39%
NOx emissions (g)	14.14	18.64	-32%
CO (g)	4.44	2.14	+52%
Phosphate emissions to water (g)	0	0.09	negative
Nitrate emissions to water (g)	0.08	12.05	-14963%

From Wotzel, Wirth, and Flake, 1999[70]

As Table 4 illustrates, many, but not all, of the changes in total manufacturing energy requirements and emissions associated with replacing traditional composite materials with hemp composites are positive. In this case, the hemp composite requires less fuel energy during manufacture and results in lower carbon dioxide, methane, and sulphur dioxide air emissions. Most of the energy required for the manufacture of the hemp composite in this example is attributed to the epoxy matrix—even when the composite is 66 percent hemp by volume, hemp accounts for only 5.3 percent of the total energy consumption. However, nitrogen oxide emissions are higher for the hemp composite, and fertilization of the hemp crop results in water emissions of phosphates and nitrates. Life-cycle analyses of other industrial hemp automotive composites show similar results.[71]

Weight savings during product use, not accounted for in the example above, could potentially result in the largest energy savings of hemp-reinforced products in transportation applications. Natural fiber components result in an average of 20 to 30 percent weight reduction—in the example above, the auto side panel constructed of hemp-epoxy is 820 grams, 27 percent lighter than the ABS equivalent. Additionally, lab research shows bio-composites can be 25 to 30 percent stronger than glass-fiber reinforced composites of the same weight.[72] Where equal or better strength is achieved with lighter-weight natural fiber composites in cars, fuel efficiency is improved for the life of the vehicle.

Carbon sequestration can be considered an additional environmental benefit during the life of the composite product.[73]

Finally, when industrial hemp-reinforced materials reach the end of their utility, a few environmental advantages still remain. In its unalloyed form, hemp is composted naturally by micro-organisms and the carbon dioxide absorbed during the growth of the plant is released back into the atmosphere. When hemp is incorporated into a composite material with polypropylene or other petroleum-based polymers, incineration is a likely end-of-life scenario. In this case, the petrochemical component adds to the total atmospheric emissions, including carbon dioxide formerly locked up in underground fossil-fuel deposits. The combustion value of the petrochemical matrix and natural fiber components combined can total as much as a quarter of the original energy used in production.[74] Even though relatively more petrochemical matrix is typically used to achieve the equivalent performance of a natural fiber-reinforced composite, glass-reinforced composites offer much lower combustion value because the glass content uses up energy during incineration.

A large number of other general construction materials, such as medium-density fiberboard, plasters, and concrete-type substances, made with industrial hemp are also on the market today. These products share many of the favorable qualities of the bio-composites discussed above, including light weight, strength, carbon sequestration, and insulating properties. Two experimental houses in Suffolk, England were built using a hemp-based product called Isochanvre in 2001; evaluation of these houses as compared to control houses of traditional masonry construction indicated that the hemp construction performed as well as the traditional construction in most categories evaluated, except that the hemp construction was somewhat inferior acoustically, superior in terms of thermal heat retention, and cost 10 percent more.[75] Thermal insulating performance and the potential for replacement of environmentally costly materials such as virgin timber and cement would be of particular interest in further environmental analyses of industrial hemp construction materials.

There is good reason to expect that composites will continue to be one of the most environmentally preferable and cost-effective applications of industrial hemp, limited in the United States by the expense of importing fiber from mostly overseas producers.

E. Other Uses

The increase in hemp acreage in Canada (from 3,200 acres in 2001 to 48,000 acres in 2006) has been driven in large part by the demand for hemp foods and cosmetics in Canada and the United States. Canadian production is focused on seed crops, which thrive at northern latitudes, are more readily processed with existing oil seed facilities than fiber crops are, and cheaper to transport and store than fiber hemp in its unprocessed state. Hemp oil is considered a superior nutritional oil, similar to flax and pumpkin seed oils. Foods and cosmetics derived from hemp oil and seed cake are currently popular (and legal) in the United States, and the Canadian Hemp Trade Alliance is invested in further researching and promoting the dietary value of omega-3 essential fatty acids, fiber, and protein found in the foods. The industry's voluntary "Test Pledge" program has successfully ensured that food products contain insignificant quantities of THC. Seed imported into the United States must also be heat-sterilized to ensure that it is not viable, which some hemp food proponents claim diminishes the seed's nutritional value and shelf life. Hemp seed is also valued as an animal feed, and, prior to prohibition in the United States, hemp oil was used in paint, inks, solvents, and other industrial applications similar to those of linseed (flax), soybean, and sunflower oils today. If hemp oil became cost-competitive it might be used more in these capacities. Hemp seed crops probably have more market potential than any other use of the low-THC *Cannabis* varieties, but the environmental significance of this market in the United States is minimal.

In western Germany between 1982 and 1995, hemp cultivation was illegal except for use as a barrier to cross-pollination in commercial beet breeding.[76] Subsequent research has shown that hemp hedges don't completely block the spread of beet pollen, but this sort of detail helps to highlight the value of inter-crop relationships in general.[77] Hemp might be an especially valuable option as a secondary crop for organic vegetable farmers, or as a value-added cover crop between either organic or conventionally grown crops, naturally reducing weeds and other pests in the process. Hemp is reportedly used in China as a barrier to repel insects from vegetable crops.[78] Researchers in Canada have reported that in rotation with soybeans, industrial hemp reduces cyst nematodes, a parasitic pest, by 80 percent.[79] (Kenaf and corn, among other crops, produce similar benefits, though maybe not to the same extent.) Dutch research has suggested similar results through hemp rotation on nematodes that damage potato crops.[80] In the Netherlands, rotation experiments with corn, hemp, winter barley, and winter rye indicated that hemp was the best crop for reducing infestations of *Cyperus esculentus*, a weedy nutgrass.[81] Fiber hemp has also reportedly suppressed aggressive agricultural plant pests quackgrass (*Agropyron repens*) and Canadian thistle (*Cirsium arvense*).[82] Complimentary crop rotations can boost the field productivity of both hemp and the subsequent rotational crop. One study reported that in the Netherlands a 10 percent increase in yield of winter wheat was observed following rotation with fiber hemp.[83] Some of the benefits seen in crop rotations with hemp—in particular, the contrast between vegetable and fiber crops—illustrate the positive value of crop diversity as opposed to the regional dominance of any single crop.

Lastly, a number of studies have identified industrial hemp as a top candidate in bioremediation, especially phytoextraction of heavy metals from industrially contaminated soils. Hemp has been used to process greywater in Australia, extensively tested in Europe for the removal of heavy metals from soil, including cadmium, lead, copper, zinc, and nickel often associated with mining, used for the cleanup of polycyclic aromatic hydrocarbons at a site in Hawaii, and cultivated on radionuclide-contaminated soils at the Chernobyl nuclear reactor site.[84] Although industrial hemp is not considered a "hyperaccumulator" of heavy metals, many researchers believe it has strong potential for use in phytoremediation because it is highly adaptable to conditions throughout the world, even moderately polluted soils, and is comparable or better in phytoremediation applications than many plants of equal economic value. Once contaminates are drawn up out of the soil into the hemp plant, it can be harvested for use in some commercial uses, such as composite insulation, industrial oil, or energy generation (contaminate levels would likely preclude its use in food or clothing).[85] Further research that may make industrial hemp a more useful plant in phytoremediation will likely include specialized hemp breeding programs and continued experimentation with agents that boost the uptake of contaminates by hemp from contaminated soil.

Part 7

Legal Issues

The United Nations Single Convention on Narcotic Drugs, adopted in 1961, requires that *Cannabis* be regulated just as opium is, but exempts industrial hemp, stating: "This Convention shall not apply to the cultivation of the cannabis plant exclusively for industrial purposes (fibre and seed) or horticultural purposes."[86]

When the Controlled Substances Act of 1970 was enacted to fulfill the treaty obligations of the United States as a signatory of the U.N. Single Convention, however, no exception was made for industrial hemp varieties of *Cannabis* in cultivation. Marijuana and its primary drug constituent, tetrahydrocannabinol (THC), were placed in the most tightly controlled group of drugs: substances defined by the Act as having a high potential for abuse and no currently accepted medical use in the United States. The newly created Drug Enforcement Administration (DEA) assumed responsibility for the regulation of industrial hemp and marijuana alike.

A growing number of states have passed legislation to allow limited research or cultivation of industrial hemp. Typically these laws do three things: (1) re-define "marijuana" as *Cannabis sativa* containing specified threshold levels of the controlled substance THC, (2) define "industrial hemp" as *Cannabis sativa* with below-threshold levels of THC, and (3) create a licensing structure for researchers or primary industrial hemp producers.

Although growing industrial hemp in the United States is technically legal, it requires a permit from the DEA. In 1994, the Hempstead Company grew just over a half acre of industrial fiber and seed hemp under a license with the U.S. Department of Agriculture's Imperial Valley Research Station in Brawley, California. Before the crop was fully mature, state officials destroyed it under orders from the state Attorney General's office.[87] The first permit issued by the DEA in recent history was to the Hawaii Industrial Hemp Research Project in 1999. Despite some early success, that project was terminated four years later due to security and legal complications (the research plot was vandalized and seed imports were lost due to administrative delays in DEA licensing and inspection).[88] The DEA has also seized and destroyed hemp crops grown on Native American tribal lands.[89]

In practice, the DEA has generally sought to expand rather than liberalize regulation of industrial hemp, even going so far as to attempt to regulate processed hemp products containing miniscule (non-psychoactive) amounts of THC.[90] Very likely, even if zero-THC strains of industrial hemp are developed for use in the United States, the DEA would push to maintain the prohibition of industrial hemp on the grounds that “problems of detection and enforcement easily justify a ban broader than the psychoactive variety of the plant,” as the court ruled in *New Hampshire Hemp Council, Inc. v. Marshall*, a case brought by hemp advocates who sought to prove that federal laws against marijuana did not prohibit the production of hemp.

The World Trade Organization recognizes industrial hemp as a legitimate crop, as do the NAFTA and GATT trade agreements, of which the United States is a signatory. Both the National Conference of State Legislators (2000) and the National Association of State Departments of Agriculture (2003) have passed resolutions asking Congress to direct the DEA to revise its policies to allow states to establish regulatory programs for industrial hemp farming and research.

The Industrial Hemp Farming Act of 2005 (HR 3037) was the first legislation introduced at the federal level to exempt industrial hemp from the Controlled Substances Act. No action was taken on the bill, and the legislation was re-introduced in 2007 (HR 1009).

Under current federal regulation, DEA-issued permits to grow *Cannabis* are subject to onerous security requirements that make the conduct of research unfeasible for all except police analytical laboratories. Permit holders can be required to maintain fencing, round-the-clock security guards, and alarm systems. Licensing requirements for industrial hemp research and commercial cultivation are similarly extensive elsewhere. In Canada, controlled research began in 1994, with commercial cultivation following four years later. Security provisions for industrial hemp cultivation include use of certified low-THC seed (licenses for seed crops are only issued to members of the Canadian Seed Growers’ Association), detailed crop testing and reporting, including submitting the locations of the storage and buyer of the crop and Global Positioning System coordinates of the crop, evidence that the applicant has no criminal record with respect to drug offenses, and minimum acreage requirements. Existing and proposed regulation of industrial hemp farming typically requires that crops are tested and approved to contain less than 0.03 percent THC before harvest.

Over-regulation of industrial hemp cultivation—for example, laws requiring that hemp seed be purchased from a certified monopoly, that legal hemp varieties contain “terminator genes,” or that buyers must be identified before farm licenses are issued—should be avoided. The potential for illicit marijuana cultivation is not considered a significant obstacle to industrial hemp farming in any other developed democracy in the world.

Part 8

Technological Feasibility

Most experts agree that, legal questions aside, the largest obstacle for profitable industrial hemp production in the United States is technological. Many of the same properties that make hemp perform so well in industrial applications—for instance, its durability and light weight—also make it expensive to process. In some countries, processing hemp for industrial use is accomplished with abundant manual labor and methods that would be environmentally unacceptable in the United States. Like many other fiber crops, long distances between the field and processing locations are often uneconomical. The entry of smaller regional processors into the market can be very difficult in the United States, where highly centralized and mechanized processing is the norm. That's a reason why, for instance, domestic virgin paper pulp is derived almost exclusively from trees. Improved environmental and economic performance is a double dividend for the large wood mills that enjoy this economy of scale.

Technological advances have frequently been sought in order to more fully or cheaply exploit the valuable natural properties of industrial hemp. For fifty years, the prohibition of industrial hemp production in the West (and, to a lesser extent, the low cost of production in the East) has been a barrier to investment in research and development of industrial hemp processing technologies. With the lifting of prohibition in other countries in the last decade, that barrier is less significant today.

Similarities between hemp and flax in the textile industry, or between hemp and other cellulosic biofuel feedstocks, might allow technological advances for the processing of one to be adapted to the other. The status of hemp in the United States is a disadvantage in highly specialized and time-sensitive research, however. If permitted again, a domestic hemp industry will face tough competition from both better-established U.S. industries (e.g. corn ethanol) and more experienced foreign producers of hemp.

Greater use of the hemp plant, including bast fiber, hurds, and seed, with development of more markets for co- and byproducts, will improve the viability of hemp industries. At the same time, more economical use of agricultural residues such as corn stalks, cereal straw, flax shives, and sugarcane bagasse might fill many of the same needs as dedicated fiber crops like hemp with greater resource efficiency.

Plant breeding and genetic engineering; streamlined harvesting, retting, and fiber separation; development of specialized processing facilities and retooling of existing facilities, including cotton mills; commercialized microbial/enzymatic processes for ethanol production; improved non-toxic pulping processes and/or improved chemical recovery in milling; further development of industrial-grade cellulosic and other bio-based plastics; and standardization at every level (to compete with highly standardized synthetic feedstocks) are all key advances that would be important to the success of the industrial hemp industry in the future.

Part 9

Conclusion

Prior to prohibition in the United States, industrial hemp was the subject of considerable excitement and speculation. The same is true today. The development of regionally and commodity-specialized industrial hemp breeds and processing capability, including complementary processing infrastructure and other innovation in the U.S. market, has been stifled through severe regulation of this plant. Examination of the unique qualities of hemp suggests that hemp prohibition affects a broad array of enterprises, ranging from those that may have mainly local economic significance, to global industries and products that are present every day in our lives. The newest technological applications of this ancient crop may be the most promising.

Nations that followed the United States in prohibiting hemp cultivation have, for the most part, rescinded these laws—some more than a decade ago. A report by the Congressional Research Service in 2005 noted that, "the United States is the only developed nation in which industrial hemp is not an established crop."[91] It seems likely that the United States cannot maintain hemp prohibition indefinitely. Reasons given for hemp prohibition in the United States make little sense today. Drug enforcement officials have argued that hemp shouldn't be grown because it looks like marijuana; in that case, the USDA should stop growing kenaf, which, as its Latin name *Hibiscus cannabinus* suggests, has a palmate leaf that can be mistaken for marijuana. Others have argued that hemp shouldn't be grown because the market for it is too speculative, and the crop may turn out to be unprofitable; in that case, corn (subsidized by the USDA at $9.4 billion in 2005) should top the list of prohibited crops.

The *Report to the Governor's Hemp and Related Fiber Crops Task Force in Kentucky* (1995) stated:

> *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….*
>
> *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.*

The Maine Agricultural and Forest Experiment Station, directed by the state legislature to report on the feasibility of industrial hemp, concluded in 2005:

> *A strong argument in favor of industrial hemp is the positive impact it has on the environment. It has been found to be a very good rotational crop, and the environmental benefits are numerous….*
>
> *Clearly, industrial hemp has a lot of potential as an alternative crop in the U.S. and Maine. However, this potential will never be realized unless the production of industrial hemp is legalized…. Until then, it is difficult to predict the future importance of industrial hemp as an agricultural crop.*[92]

In North Dakota, where officials are leading the effort to reinstitute hemp cultivation, a white paper commissioned by the state legislature in 1998 optimistically summarized, "Basically, industrial hemp is easier on the land than any other crops except for legumes such as clover and alfalfa."[93]

Considering the whole life cycle of industrial hemp products, below-average inputs required during the cultivation of hemp are only a small part of the potential environmental benefit. Comparisons of industrial hemp to hydrocarbon or other conventional industrial feedstocks show that, generally, hemp requires substantially less energy for manufacturing, often is suited to less-toxic means of processing, and provides competitive product performance (especially in terms of durability, light weight, and strength), greater recyclability and/or biodegradability, and a number of value-added applications for byproducts and waste materials at either end of the product life cycle. Performance areas where industrial hemp may have higher average environmental costs than comparable raw materials result from the use of water and fertilizer during the growth stage, greater frequency of soil disturbance (erosion) during cultivation as compared to forests and some field crops, and often relatively high water use during the manufacturing stage of hemp products. Unlike petrochemical feedstocks, industrial hemp production offsets carbon dioxide emissions, helping to close the carbon cycle. Overall, social pressure and government mandates for lower dioxin production, lower greenhouse gas emissions, greater bio-based product procurement, and a number of other environmental regulations seem to directly contradict the wisdom of prohibiting an evidently useful and unique crop like hemp.

Ultimately, the environmental costs incurred by the prohibition of hemp cultivation in the United States cannot be calculated purely in the abstract. The full potential for industrial hemp in domestic agriculture and industry can only be tested by unrestricted inclusion in the U.S. market, along with other top biological feedstocks.

About the Author

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Appendix

Hemp Fact and Fiction

Many dramatic claims about the productivity and uses of the hemp crop originated in early promotional articles. Three sources in particular have been sited in numerous subsequent writings on hemp: two articles by Lyster H. Dewey in the *Yearbook of the U.S. Department of Agriculture: 1913* and the USDA's *Bulletin No. 404*, a 1937 *Mechanical Engineering* article, "Flax and Hemp: From the Seed to the Loom," and a 1938 *Popular Mechanics* article about hemp titled "New Billion-Dollar Crop." While much of the research represented in these works may have been accurate at the time, a few statements deserve close criticism, including:

> *[Hemp] produc[es] a larger amount of dry vegetable matter than any other crop in temperate climates...*[94]

> *Every tract of 10,000 acres which is devoted to hemp raising year by year is equivalent to a sustained pulp-producing capacity of 40,500 acres of average pulp-wood lands.*[95]

> *Hemp, the strongest of the vegetable fibers, gives the greatest production per acre and requires the least attention. It not only requires no weeding, but also kills off all the weeds and leaves the soil in splendid condition for the following crop. This, irrespective of its own monetary value, makes it a desirable crop to grow.*[96]

> *[Hemp] is used to produce more than 5,000 textile products, ranging from rope to fine laces, and the woody "hurds" remaining after the fiber has been removed contain more than seventy-seven per cent cellulose, and can be used to produce more than 25,000 products, ranging from dynamite to Cellophane…*[97]

Some hemp advocates have claimed that the plant is the most productive plant on Earth. In fact, like any plant, hemp productivity depends on a number of factors, including growing conditions and genetic composition, which make broad claims like this pointless. Even the more conservative claim that hemp produces more dry vegetable matter than other temperate crops is an over-estimation. Many other crops, including corn, sugar cane, and kenaf, produce greater biomass per acre, though agricultural requirements for these crops may also differ.

Growing conditions, species selection, and genetic variation may also explain the inaccuracy of the claim that 40,500 acres of trees are needed to produce the same amount of paper as 10,000 acres of hemp can produce. (This statement is often summarized as "hemp produces four times as much paper as trees.") There are certainly places in the world, for example, at high elevations, where this might be true. However, whether or not this figure accurately described production of U.S. forests (either hardwood, softwood, or a combination of both) at the time of the statement almost a century ago, the generalization does not hold true for forests grown commercially for paper pulp in the United States today. Cottonwood plantations in the United States produce more than six tons of biomass per acre annually, with a pulp yield of around 45 percent. Hemp might produce an average of 3.5 tons of biomass per acre in four to five months, with a pulp yield somewhere between 30 and 55 percent, depending on the process used. Hemp produces biomass faster, with a harvest in months rather than years, but faster isn't necessarily better—fast growth comes at a cost.

Hemp does not produce the strongest or longest fiber, nor does it have the highest cellulose content. However, it ranks very high in all of these categories, and in some cases requires less resource-intensive cultivation and processing (it is true, for instance, that the crop is vigorously weed-resistant). Cellulose content depends on the variety and growing conditions of the crop, and is highest in the outer part of the stem. The outer bark (bast fiber) of the hemp plant averages 60 percent cellulose, while the inner core (hurd) contains approximately 45 percent cellulose.

Finally, the number of products that can be made with hemp is clearly an issue of invention, not scientific fact.

Other hemp fiction includes the following:

- The Declaration of Independence, the original United States Constitution, the Bill of Rights, and/or the Articles of Confederation were written on hemp.
  (Fact: like most important documents of the time, all of the above were written on parchment derived of animal skins, though some notes and initial drafts were written on hemp.[98])

- Hemp produces the longest fiber of any textile crop.
  (Fact: cotton and flax are longer.)

- The Gutenberg Bible and/or the original King James Bible were printed on hemp.
  (Fact: The "original" King James Bible is a topic of religious and historic debate; copies of these bibles were probably made on all types of paper and vellum (skin). According to the British Library, Gutenberg produced about 135 copies on flax linen rag paper and about 45 on vellum.[99])

- Hemp fixes nitrogen in the ground, and/or makes the soil rich in nutrients.
  (Fact: Hemp grown for fiber requires nitrogen supplements, which is why it is often recommended as a rotational crop following nitrogen-fixing crops. All crops draw nutrients out of the soil, and hemp is no exception. Agricultural practices that leave as much of the foliage and other excess plant matter in the field are sometimes used to mitigate the relatively high uptake of nitrogen by hemp crops.)

- Around 1815, Thomas Jefferson acquired the first U.S. patent ever issued for his hemp break, a modified threshing machine used to separate the hemp stalk into usable hurds and fiber.

(Fact: Thomas Jefferson, like George Washington, cultivated hemp and believed it was superior to linen and tobacco as a crop. As Secretary of State he drafted the first federal patent laws and oversaw the first patents—he also modified a threshing machine to break hemp, of which he wrote: "Something of this kind has been so long wanted by the cultivators of hemp, that as soon as I can speak of its effect with certainty I shall probably describe it anonymously in the public papers, in order to forestall the prevention of its use by some interloping patentee."[100])

- The original Levi's jeans were made of hemp.
  (Fact: According to Levi Strauss & Co., the denim at the time was made of cotton.[101] Records of the early company history were lost in the 1906 San Francisco earthquake, leading some people to speculate that the early jeans were made of hemp canvas rather than denim, but Levi's historians have since shown that is not true.)

- Hemp is chemically the same as marijuana.
  (Fact: Most laws in other countries regulate industrial hemp to ensure that it contains only insignificant amounts of THC (delta-9-tetrahydrocannabinol), the psychoactive component of marijuana. Typically, hemp also contains high levels of CBD (cannabidiol), a chemical in *Cannabis* that counteracts the effect of THC.)

[1] A small amount of kenaf is produced in the United States; the United States has a growing production of flax for seed, but not for fiber.

[2] James M. Dempsey, *Fiber Crops* (University of Florida, 1975), pp. 50–51.

[3] Lyster H. Dewey, *Yearbook of the United States Department of Agriculture: 1913.*

[4] Bill Kovarik, “Henry Ford, Charles F. Kettering and the Fuel of the Future,” *Automotive History Review*, no. 32 (Spring 1998), pp. 7–27.

[5] Lyster H. Dewey and Jason L. Merrill, “Hemp Hurds As Paper-Making Material,” *United States Department of Agriculture Bulletin No. 404* (Washington D.C., October 14, 1916).

[6] H.T. Nugent, “Report of Survey: Commercialized Hemp (1934–35 Crop) in the State of Minnesota,” Memo to Harry J. Anslinger, Commissioner of Narcotics (Washington D.C., October 22, 1938). Reproduced in the Schaffer Drug Library, www.druglibrary.org/SCHAFFER/hemp/taxact/nugent1.htm.

[7] John Craig Lupien, “Unraveling an American Dilemma: The Demonization of Marihuana,” Masters thesis prepared for the Division of Humanities of Pepperdine University, April 1995. Reproduced in the Schaffer Drug Library, online.

[8] George A. Lower, “Flax and Hemp: From the Seed to the Loom,” *Mechanical Engineering*, February 26, 1937; and “New Billion-Dollar Crop,” *Popular Mechanics*, February 1938. (The Marihuana Tax Act of 1937 had already been in effect since October of the previous year.)

[9] Section 1(b) of the *Marihuana Tax Act of 1937* reads: “The term ‘marihuana’ means all parts of the plant *Cannabis sativa L.*, whether growing or not; the seeds thereof; the resin extracted from any part of such plant; and every compound, manufacture, salt, derivative, mixture, or preparation of such plant, its seeds, or resin—but shall not include the mature stalks of such plant, fiber produced from such stalks, oil or cake made from the seeds of such plant, any other compound, manufacture, salt, derivative, mixture, or preparation of such mature stalks (except the resin extracted therefrom), fiber, oil, or cake, or the sterilized seed of such plant which is incapable of germination.”

[10] Lupien, “Unraveling an American Dilemma.”

[11] *Yearbook of United States Agriculture*, 1917, in John Roulac, *Hemp Horizons* (White River Junction, Vermont: Chelsea Green Publishing Company, 1997), p. 35

[12] 1945 agricultural statistics reported in Dempsey, *Fiber Crops*.

[13] Arizona: Mark J. Cochran et al., (2000); Colorado: Boulder Hemp Initiative Project (1994); Hawaii: Gertraude Roth-Li (1996); Illinois: Report to the House of Representatives (2000); Kentucky: Sara McNulty (1995) and Eric C. Thompson et al. (1998); Maine: Maine Agricultural Center (2006); Minnesota: Jim L. Bowyer (2001); Missouri: Richard Lawrence

Miller (1991); North Dakota: David G. Kraenzel et al. (1998); Oregon: Daryl T. Ehrensing (1998); Vermont: Kasea Hill, Nathan Boshard-Blackey and Jim Simson (2000); Wisconsin: Carl Houtman (1997). A study authorized by the legislature of North Carolina is scheduled for release in 2007.

[14] United States Department of Agriculture (2000).

[15] In the case of the USDA study (2000), conclusions about the economic non-viability of domestic industrial hemp production also relied on incomplete datasets on raw and processed hemp imports and largely ignored potential future markets—instead, it essentially equated hemp with the (nonexistent) domestic textile flax market.

[16] N. Cherret et al., "Ecological Footprint and Water Analysis of Cotton, Hemp and Polyester: Report prepared for and reviewed by BioRegional Development Group and World Wide Fund for Nature, Cymru" (Stockholm, Sweden: Stockholm Environment Institute, 2005).

[17] The World Wildlife Fund reports that only 2.4 percent of the world's arable land is planted with cotton, but the crop accounts for 24 percent of the world's insecticide market and 11 percent of the sale of global pesticides. Cotton consumption (including water used in the manufacturing process) accounts for 2.6 percent of total global water consumption according to A.K. Chapagain et al., "The water footprint of cotton consumption," *Value of Water: Research Report Series*, no. 18 (UNESCO-IHE Institute for Water Education: September 2005).

[18] David Pimentel, "Environmental and Economic Costs of the Application of Pesticides Primarily in the United States," *Environment, Development and Sustainability*, vol. 7, no. 2 (June 2005). The study reported that the major economic and environmental losses due to the application of pesticides in the USA were: public health, $1.1 billion per year; pesticide resistance in pests, $1.5 billion; crop losses caused by pesticides, $1.4 billion; bird losses due to pesticides, $2.2 billion; and groundwater contamination, $2.0 billion. The analysis is controversial because it assigns monetary value to some non-market resources, such as wildlife.

[19] Carpenter and Gianessi (2001) reported that herbicide application rates for conventional cotton vary from 4.4 to 7.1 lbs. formulated product per acre compared to 2.2 to 3.6 pounds per acre for glyphosate-tolerant varieties. Huang et al., (2001) reported that in China, the world's top cotton-producing nation, Bt cotton (genetically engineered for protection from insect pests) reduced pesticide use from 49 to 14 lbs. formulated product per acre and the number of times the crop was sprayed from 20 to 7. Cited in R. H. Phipps and J. R. Park, "Environmental Benefits of Genetically Modified Crops: Global and European Perspectives on Their Ability to Reduce Pesticide Use," *Journal of Animal and Feed Sciences*, vol. 11 (2002). Other reports, however, suggest that over time, herbicide-tolerant cotton varieties result in increased herbicide use, as weeds adapt to the herbicide.

[20] Hayo M. G. van der Werf, "Life Cycle Analysis of field production of fibre hemp, the effect of production practices on environmental impacts," *Euphytica* (2004), pp. 13–23.

[21] Gary Klein et al., California Energy Commission, *California's Water-Energy Relationship: Final Staff Report*, www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF, November 2005, pp. 12–14

[22] Jim Wells et al., General Accounting Office, Report to the Ranking Democratic Member, Committee on Agriculture, Nutrition and Forestry, U.S. Senate, *Natural Gas: Domestic*

Nitrogen Fertilizer Production Depends on Natural Gas Availability and Prices, www.gao.gov/new.items/d031148.pdf, September 2003.

23 Stephen R. Wilson, Testimony to the United States Senate Committee on Energy and Natural Resources, energy.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=1529&Witness_ID=4326, February 16, 2006.

24 Tore K. Jenssen and Gunnar Kongshaug, "Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production," The International Fertilizer Society, Proceeding 509 (Oslo, Norway: 2003).

25 Energy Information Administration, *Emissions of Greenhouse Gasses in the United States 2005*, www.eia.doe.gov/oiaf/1605/ggrpt/ghgeuse_table.html.

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[37] United States Department of Justice, Bureau of Justice Statistics, *Online Sourcebook*, www.albany.edu/sourcebook/ind/DRUGS.Asset_seizure.1.html.

[38] van der Werf, "Life Cycle Analysis of field production of fibre hemp."

[39] Jack Herer, *The Emperor Wears No Clothes* (1991), p. 136.

[40] Paper Task Force, *Non-wood Fiber Sources (White Paper No. 13)* (2006), p. 42; and Jim L. Bowyer, *Industrial Hemp as a Papermaking Raw Material in Minnesota: Technical, Economic, and Environmental Considerations* (2001), p. 26.

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[42] Bowyer, *Industrial Hemp as a Papermaking Raw Material in Minnesota*, p. 34.

[43] Carl Houtman, *Market Analysis for Hemp Fiber as a Feed Stock for Papermaking* (Madison, Wisconsin: USDA-FS Forest Products Laboratory, 1997).

[44] Proto et al. (2000) and Soth et al. (1999) in Chapagain et al., "The water footprint of cotton consumption," p. 10.

[45] Richard A. Adams, "The U.S. Hemp Market: An Economic Examination of the Hemp Industry," Baker College Center for Graduate Studies.

[46] United States Department of Agriculture, Economic Research Service, *Cotton and Wool Situation and Outlook Yearbook*, CWS-2006 (Washington D.C., November 2006).

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[49] United States Department of Agriculture, *Agricultural Research Resource Management Survey*, www.ers.usda.gov/Data/ARMS/app/Crop.aspx.

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[54] Environmental Working Group, *Farm Subsidy Database*, www.ewg.org/farm/progdetail.php?fips=06000&progcode=cotton.

[55] Renee Sharp et al., Environmental Working Group, *California Water Subsidies*, www.ewg.org/reports/watersubsidies.

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the crop for fuel, Pimentel and Patzek found: “Ethanol production using corn grain required 29 percent more fossil energy than the ethanol fuel produced. Ethanol production using switchgrass required 50 percent more fossil energy than the ethanol fuel produced. Ethanol production using wood biomass required 57 percent more fossil energy than the ethanol fuel produced. Biodiesel production using soybean required 27 percent more fossil energy than the biodiesel fuel produced (note: the energy yield from soy oil per hectare is far lower than the ethanol yield from corn). Biodiesel production using sunflower required 118 percent more fossil energy than the biodiesel fuel produced.” A critical analysis of this study is provided by David Morris, *The Carbohydrate Economy, Biofuels and the Net Energy Debate* (Institute for Local Self-Reliance, August 2005) and Hosein Shapouri, James A. Duffield and Michael Wang, *The Energy Balance of Corn Ethanol: An Update*, Office of Energy Policy and New Uses, Agricultural Economic Report, no. 813 (United States Department of Agriculture).

[57] Michael Wang, Argonne National Laboratory, cited in Energy Information Administration, *Emissions of Greenhouse Gasses in the United States 2005*.

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