Does the use of Cannabis species for the production of biodiesel and ethanol, result in higher yields of ethanol than competing cellulotic crops, including Zea mays?

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The Case for Hemp as a Biofuel

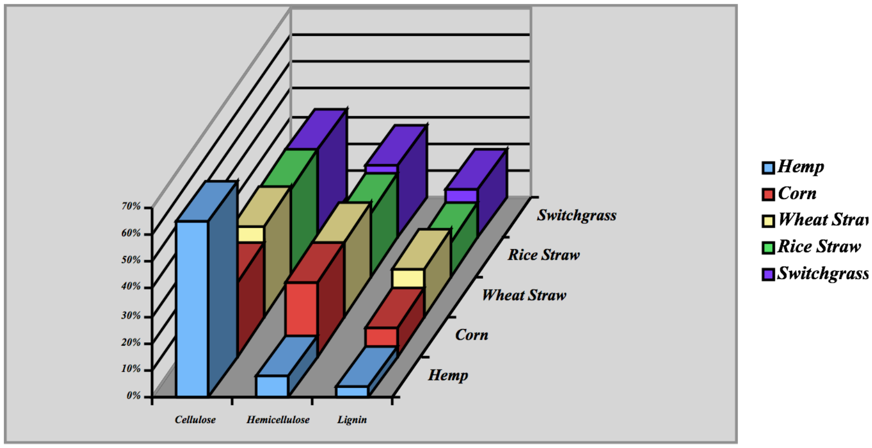
With the worldwide increase in demand for oil, concern over the environmental impact of the use of fossil fuels, concern over increasing fuel prices and uncontrolled profit margins by just a few select corporate entities, alternatives to dependence on Arabian oil supplies are actively being sought. For stationary heavy demand energy needs, nuclear, solar, wind and hydroelectric energy options are increasing daily. An alternative to petroleum for mobile energy demands has not yet been effectively met. Hydrogen and biofuel alternatives continue to be explored by many researchers.

In most of the world the male-sexed plant, *Cannabis sativa* is grown as a source of biomass with a variety of uses.[a] While the female-sexed plant is well known for its psychoactive effects in Humans, the psychoactive agent in the male-sexed plant is nearly undetectable.[b] As of 2008, United States Federal statutes forbid the cultivation of any plant in the *Cannabis* genus for any purpose within the borders of the United States or her possessions.[c] As many as thirty different plant species have Cannabis-like characteristics as it relates to cellulose density per unit volume. Like Hemp, these species are actively cultivated in most of the rest of the world, but commercial cultivation is forbidden in the United States despite the absence of psychoactive agents. These species include: *Musa textilis*, *Agave sisalana*, *Furcraea gigantea*, *Phormium tenax*, *Crotalaria juncea*, *Corchorus capsularis*, *Apocynum cannabinum*, & *Sansevieria cylindrica*. Interestingly, the cultivation of *Humulus lupulus*, a member of the same Cannabaceae family as *Cannabis* is not forbidden in the United States, presumably because of its usefulness in the brewing process of ales.[d]

Corn ethanol is the biofuel most favored by current United States government subsidies for renewable fuels. Hemp is an improvement over corn-based ethanol on several counts: Higher soil conservation, nearly non-existent herbicide & pesticide requirements, Higher yields, and greater suitability for cellulosic ethanol production, as opposed to either grains or corn.[e] Comparing dried biomass yields of Hemp and Corn, Hemp produces $305\frac{Ki\log rams}{Hectacre}$ while Corn only produces $145\frac{Ki\log rams}{Hectacre}$.[f] When compared to other plant species of active interest in biofuel production, Hemp derives *100%* more cellulose than species under active investigation.[g]

	Cellulose	Hemicellulose	Lignin
Hemp	64.8 %	7.7%	4.3 %
Wheat Straw	34%	27.6%	18%
Switchgrass	32.5%	26.4%	17.8%
Rice Straw	32.1%	24.0%	12.5%
Corn	28%	28%	11%

Chemical composition of Industrial Hemp as compared to other plant matter



Production costs for Corn based ethanol approaches *$85* per *160 Liters.* Production costs for Hemp derived ethanol is only *$43* per *160 Liters*.[h] In 2006 the State of California dedicated *20,234 square Kilometers* of cropland to vineyards supporting that State's wine industry. If $10{,}117 Km^2$ of cropland were dedicated to Hemp production, *3,785,412,000 Liters* of ethanol could be produced.[g]

Gasoline yields $34.8 \frac{Megajoules}{Liter}$ of energy, ethanol yields only $23.5 \frac{Megajoules}{Liter}$ of energy. *Jet-A* the primary aviation fuel worldwide yields $35.1 \frac{Megajoules}{Liter}$, and Diesel yields $38.6 \frac{Megajoules}{Liter}$. In 2006, the United States alone consumed *500 Billion Liters* of gasoline.[i] To replace the same energy requirement, *750 Billion Liters* of ethanol would have to be produced, which would require $25{,}000 Km^2$ of croplands dedicated to Hemp cultivation. In order to produce the same volume of ethanol using Corn as the biomass substrate, $62{,}500 Km^2$ of croplands would need to be dedicated to the cultivation of *Zea mays* for fuel production.[g]

Cannabis sativa and its related species provide denser cellulose content than does *Zea mays*, higher sugar content, and derives higher ethanol yields per metric-tonne at lower costs.

How to Make Ethanol Fuel

Ethanol production from plant biomass consists of four major operations:

I. Pretreatment.
II. Hydrolysis.
III. Fermentation.
IV. Product Separation and Purification.[g]

Pretreatment:

Pretreatment is necessary to alter the cellular structure of the biomass at hand.
Specifically, Lignin presents a significant stumbling-block to the fermentation of celluotic material. Pretreatment procedures are primarily aimed at breaking-down Lignin. Pretreatment begins by reducing the size of the biomass to particle size creating a pulp. The pulp is then subjected to high pressure steam explosions at *210C*, exceeding the trauma inflicted by pressure cooking. The hot pulp is then immerged in a Sulferic Acid bath, followed by a Sodium Hydroxide bath. As the pulp is cooled it is subjected to baths and sprays of Hydrogen Peroxid, Hydrochloric Acid and Ammonia. Finally, it is subjected to a bath of Dimethyl Sulfoxide *(DMSO)* which acts as an emulsifier. The expense of these chemical treatments are only cost effective when large volumes of biomass is processed and the chemicals are continually reclaimed and recycled.

Hydrolysis:

Hydrolysis is the process by which Glucose and other carbohydrate polymers are broken down into monomer simple sugars for fermentation. Hydrolysis is accomplished by subjecting the pretreated pulp to high pressure steam and hot water showers, sprays and baths. Cellulase, enzymes produced chiefly by fungi and bacteria is introduced converting the pretreated cellulose to glucose and a variety of monomers.

Fermentation:

Fermentation is process of converting sugars and cellulose directly to ethanol through the metabolic processes of various yeasts and fungi. Following hydrolysis the pulp is placed in pools of water at *37C* to *42C*, generally in an anaerobic environment and exposed to fungi. *Saccharomyces pombe, Saccharomyces cerevisiae, Saccharomyces amucae, Saccharomyces pastorianus, Brettanomyces* & *Kluveromyces lactis,* are frequently used strains of yeast. Some strains of yeast have been developed and patented specifically for the purpose of fermenting cellulose directly to ethanol or methanol. Variations in the fermentation process are often considered trade secrets.

Product Separation and Purification:

After fermenting for *14* to *20 days*, the fermented solution is drained away from the pulp and moved to a distiller. Here the temperature in raised just enough to cause the ethanol to evaporate. The evaporate is captured in a distilling coil and cooled, re-liquidating the pure ethanol. The water left behind is recycled, and the pulp is composted. Following distillation, the ethanol is purified using a physical absorption process and then Benzene is added to the ethanol rendering it undrinkable for tax and duty purposes.

Gasification, acid hydrolysis and a technology utilizing engineered enzymes to convert cellulose to glucose, which is then fermented to make alcohol, are current methods under most rigorous investigation. Conversion of cellulose directly to ethanol remains the Holy Grail of Biofuel technologies.[g] Significant progress has been made in developing this technology using bacteria and a variety of yeasts and fungi, however significant commercial applications are still some years away. Successful development of *this* technology will lead to substantial process cost savings.

Prelimenary prototype production runs have rendered *375* to *700 Liters* of ethanol per *Metric-tonne* of Hemp in European testing facilities.[j]

Conclusion

The challenge of stripping Lignin from Lignin-bound cellulotic plant matter is the primary complexity that must be overcome prior to the direct conversion of cellulose to ethanol. Certain fungi and yeasts have been developed and patented that will accomplish this task, but so far there is yet to be a technology developed which will do so at cost efficiency. Once this technology has evolved sufficiently to be cost effective at large scales, we conclude that *Cannabis sativa* and its related species is a superior cultivar for biofuel production. Hemp exhibits far superior ethanol yields per unit biomass compared to *Zea mays* (Corn) or *Panicum virgatum* (Switchgrass), which are currently the two most supported biofuel cultivars by the United States government.

With ethanol production technologies being used in 2008, *Beta vulgaris* (Sugar Beets) is probably the cultivar of choice for ethanol production, as its large tubar-like root biomass is converted to sucrose in a very simple, inexpensive, single-step process. This makes ethanol production extremely easy consisting of only the fermentation and distillation processes. The drawback to large cultivations of *Beta vulgaris* for ethanol production is the skill required to cultivate large land-tracts of the crop, and the very short timeline between harvesting the crop and processing the yield, as the high sucrose content lends itself to rapid decay of the root once the root is removed from the soil.

Works Cited

a. Rawson, Jean M. *Hemp as an Agricultural Commodity.* Congressional Research Service. Library of Congress. Washington, DC. July 8, 2005. pp. 3-4.

b. United States Code. 2006. Schedule No. 1089, Section 2, Subsection (3). Industrial Hemp Regulations and amendment to Schedule II of the Controlled Drugs and Substances Act, December 27, 1997.

c. United States Code. 2006. Title 18. Chapter 13.

d. West, David P. Ph.D. *Hemp and Marijuana: Myths & Realities.* North American Industrial Hemp Council. Madison. 1998.

e. Smith-Heisters, Skaidra. *Illegally Green: Environmental Costs of Hemp Prohibition.* Reason Foundation. Los Angeles. 2007.

f. Harris, Stuart G. *CTUIR Renewable Energy Feasibility Study Final Report.* Dept of Science & Engineering. Confederated Tribes of the Umatilla Indian Reservation. National Renewable Energy Laboratory. Department of Energy. United States Government. 2005.

g. Castleman, Tim. *Hemp Biomass for Energy.* Arizona Fuel & Fiber Company. Mesa. 2006.

h. Hoover, Amy. *New Fuel Ideas.* Evolution, Ecology and Oganismal Biology. Ohio State University. 2008.

i. Wikipedia On-Line Encyclopedia. *http://en.wikipedia.org/wiki/Gasoline*. Accessed 02 June 2008.

j. Mosier, Nathan. *Features of Promising Technologies for Pretreatment of Lignocellulosic Biomass.* Bioresource Technology. Science Direct. 2004.