Hemp: An Energy Crop to Transform Kentucky and West Virginia

2014 White Paper

P

Presented by
Kentucky Hemp Growers Cooperative Association
West Virginia Hemp Growers Cooperative Association

KHGCA Kentucky Hemp

WVHGCA West Virginia Hemp

About The Kentucky Hemp Growers' Cooperative Association (KHGCA)

The KHGCA (http://www.kentuckyhempgca.org/about/khgca-organization/) is a member-owned corporation providing assistance, information, and resources to partner-members endeavoring to produce or sell industrial hemp. Incorporated in 1994, the Cooperative seeks to uphold a tradition of legal and profitable hemp production in Kentucky. The original Kentucky hemp cooperative association was organized during WWII and produced high-quality industrial hemp for vital military stores, including oil, textiles, and cordage for naval vehicles and airplanes. The KHGCA is organized for agricultural purposes and to stimulate economic enrichment in the region. A sister of KHGCA, the West Virginia Hemp Growers' Cooperative Association intends to expand the potential economic benefits of the hemp industry across the state. As an active member of the Central Appalachia Sustainable Economies (CASE) network, the cooperative seeks to ensure a resilient West Virginia economy by stimulating the emergence of dense industry clusters by way of Integrated Energy Park development.

About the Authors

Katherine M. Andrews, Ph.D., is a Ronin Institute Research Scholar working in the areas of Translational Science and Integrated Energy Systems (http://ronininstitute.org/research-scholars/katherine-andrews/). With a doctorate in biochemistry from the University of Illinois, she completed post-doctoral training in neuroscience and a faculty post in genetics, at Washington University in St. Louis, before moving to the private sector and taking on a series of cross-disciplinary leadership roles that bridged business and science, in fields ranging from computational drug design for the pharmaceutical industry to metabolic engineering of microbes for the production of biofuels. In 2007, she served as co-principal investigator to win a $135 million federal award that launched the DOE Joint Bioenergy Institute (Emeryville, CA), while managing Sandia National Laboratories' Department of Computational Biology. Now based in the Bluegrass Region of Kentucky, she is an executive level strategist who works with all sectors to redefine business models, attract investors, and optimize research and development programs based on both technical and market knowledge.

Alex Donesky is currently a student at Wesleyan University in Middletown, Connecticut where he studies Economics, History and Government. He served as a 2013 Intern with Patriot Bioenergy Corporation and with Sustainable Williamson, studying renewable and biomass energy projects and the development of sustainable methods and technologies.

Roger Ford is an entrepreneur with over 25 years of experience in governmental relations, political strategy, and economic and business development. He is CEO of Patriot Bioenergy Corporation and a partner in Emergy Holdings, Inc. and TerraGas, LLC. He graduated from The University of Pikeville and is working to complete his Masters in National Security at American Military University. Ford is a member of the Southern States Energy Board's Clean Coal and Energy Technology Collaboration Committee, the Board of Directors for the Kentucky Hemp Growers' Cooperative Association, the Board of Directors of the West Virginia Hemp Growers' Cooperative Association, and the Chairman of Sustainable Pike County and Sustainable Williamson, which are both part of the Central Appalachian Sustainable Economies (CASE) Network.

J. Eric Mathis has been at the forefront of initiatives to bridge the gap between the fossil fuel and renewable energy industries through the development and implementation of innovative finance and business models. These models are designed to be beneficial to both industries, creating mutually productive economic linkages between the fossil fuel and renewable industries, and most importantly between the surrounding communities. As an active member of the community, he is helping to develop a comprehensive project entitled Sustainable Williamson that emphasizes health and wellness as a key component for economic revitalization. Using Sustainable Williamson as a template, his most recent endeavor is participating in the creation and implementation of the Central Appalachian Sustainable Economies (CASE) network, an interactive regional network of innovators cultivating new ideas and resources in central Appalachia to grow healthy communities.

Hemp: An Energy Crop to Transform Kentucky and West Virginia

Katherine M. Andrews, Alex Donesky, Roger Ford, and J. Eric Mathis

Executive Summary

Industrial hemp (*Cannabis sativa L.*) has been grown and evaluated for energy purposes in the United States, Ireland, Spain, Germany, Poland, Sweden, and many other countries[1]. A proven Kentucky crop possessing favorable characteristics of high land use efficiency, low requirement for pesticides, and high drought tolerance, hemp offers to comprehensive solution to its current economic and energy challenges. In 2013, the Kentucky Legislature signed Senate Bill 50 (SB50) into law, opening the door for a regulatory framework to be established for farmers to become licensed to grow hemp. Twenty other states have passed similar hemp legislation to re-introduce industrial hemp as an agricultural crop for harvest and manufacturing of diverse products, including oil, structural fiber, and materials. We suggest that hemp is a viable biomass feedstock for the production of fuels, industrial chemicals, advanced materials, and electricity in Kentucky and neighboring states such as West Virginia. Here, we present the results of a preliminary study performed by Patriot Bioenergy Corporation, in collaboration with the Kentucky Hemp Growers Cooperative Association and West Virginia Hemp Growers Association, to assess the technical feasibility of co-firing of hemp with coal for power generation. We suggest that the accelerated adoption of hemp to grow the increasingly intertwined energy, agricultural and manufacturing sectors will particularly benefit rural regions.

Biomass co-firing is an attractive near term strategy for existing power plants to achieve reduction of carbon dioxide and other pollutants in compliance with new regulations on emissions.

The Energy Challenge

Major technological and commercial hurdles must be overcome in order to strengthen the struggling economies of Kentucky and West Virginia, in a rapidly changing energy landscape in which fossil-derived energy sources are being replaced by renewables. Notably, the use of coal-fired generators has dramatically declined in the Southeast, with the region experiencing the largest shift from coal to natural gas in the United States from 2011 to 2013[2]. As top energy exporters, these states have relied historically on coal as the predominant feedstock for electricity generation to fill local power needs, and for export to other states and the international markets[3,4].

New regulations and policies have reduced the demand for coal, and plants are closing due to a lack of cost effective ways to reduce emissions, particular sulfur and mercury[5]. As a result, regions of the states where coal is mined and converted in power plants are suffering from job losses and an uncertain future. In order to compete nationally and internationally, we must undertake an 'all-of-the-above' strategy for energy production and export that includes

renewables and biomass and supports growth of the economy in rural Kentucky and Central Appalachia.

Along with global competition from other energy resources such as natural gas, the coal power industry also faces new regulatory mandates and public policies[6] that require adaptation by the industry to ensure that coal remains viable. Despite higher heat values than Western coal, Appalachian coal is particularly at risk due to its mining costs, sulfur content, and heavy metal composition. Coal mined from the Illinois and Appalachian Coal Basins would benefit from the blending with biomass.

Power facilities such as the E.W. Brown Generating Station in Central Kentucky, are optimally co-located with thousands of acres of land suitable for hemp cultivation.

Photo: K. Andrews © 2010

By blending coal with biomass materials such as hemp, sulfur emissions from power generation can be reduced and less valuable coal that is high in sulfur can remain competitive. While significant public and private investments around the nation have accelerated the development of biomass energy crops and processes for transportation fuels, chemicals, and electricity, no major biomass crops have been adopted in Kentucky to date. State-funded research centers have prioritized combustion and carbon sequestration over biofuels[7]; and although the U.S. Department of Energy has named I-65 'the nation's first biofuels corridor[8][9], only one ethanol plant[10] and one biodiesel[11] plant currently operate in Kentucky at a commercial scale. There are currently no publicly announced plans for second generation "cellulosic" fuel production, made possible through intense research and engineering in the past five years[12][13][14][15]. West Virginia passed SB447 in 2002 and helped to establish early guidelines for hemp production in the United States. The 2013 signing of Kentucky's SB50 into law further enables the potential of hemp as an energy crop to be realized throughout the region and accelerated by integration with existing energy production practices.

Hemp: A Biomass Energy Crop

Industrial hemp has been studied extensively by researchers at national laboratories, universities, and leading international research institutions, for its potential as a bioenergy crop[16][17][18][19][20][21]. Biomass crops have been prioritized by the United States Departments of Energy (DOE) and Agriculture (USDA)[22] for development across the nation due to their great potential for increasing the share of domestic renewable energy. Hemp biomass is routinely included in comprehensive biomass evaluations for specific industrial applications[23][24][25][26], and hemp's molecular structure and chemistry have now been characterized for a variety of purposes[27][28][29][30]. A multitude of recent publications in science and engineering journals have reported the successful conversion of hemp to transportation fuels, chemicals, biodegradable polymers, and a broad range of advanced materials[31][32][33][34][35][36][37][38][39][40][41][42]. Exciting new developments include the use of exfoliated hemp to produce high capacitance graphene nano-sheets for use in large-scale production of energy storage devices[43].

While few annual crops can easily be rotated with food and feed crops – a critical parameter for sustainable energy production - crops for which the whole plant biomass can be harvested and used for energy production can result in high land use efficiency. Detailed life cycle analyses[44][45], agronomic studies[46][47][48][49][50], environmental impact evaluations[51][52][53], and techno-economic assessments[54][55] of hemp under a variety of conditions indicate that industrial hemp is viable for accelerated development and integration[56] at the commercial scale for multiple industrial applications.

Refined Biomass for Co-Firing and Power Generation

Now demonstrated at more than 150 power-generating sites around the globe[57], biomass co-firing is attractive as a viable near term strategy for existing power plants to adopt in order to achieve reduced emissions of carbon dioxide, sulfur and other pollutants in compliance with new regulations on emissions. Co-firing has the advantages of lowered pollutant emissions, improved carbon footprint due to the consumption of CO_2 by biomass crops, low capital costs as an add-on, and fuel flexibility to accommodate a range of usable biomass fuels depending on regional, seasonal, and weather factors[58].

Scientists at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, have evaluated co-firing in all types of boilers used by electric utilities and demonstrated that boiler efficiency is not lost when co-firing biomass blends[59]. Refining of biomass by torrefaction[60], steam explosion[61][62][63], hydrothermal carbonization[64][65][66][67], and other methods increases the energy density of biomass and yields a more coal-like, hydrophobic consistency along with improved storage and handling[68]. As for fossil fuels, the key characteristics of biomass fuels are the thermal capacity along with physical, chemical, and combustion properties. Refined biomass to be used for combustion must be characterized for properties such as total ash content, melting behavior, chemical composition, and heat value. Here, we present the results of a preliminary technical feasibility study of hemp combustion, performed in parallel with higher sulfur coal that is typical of Appalachian and Illinois coals.

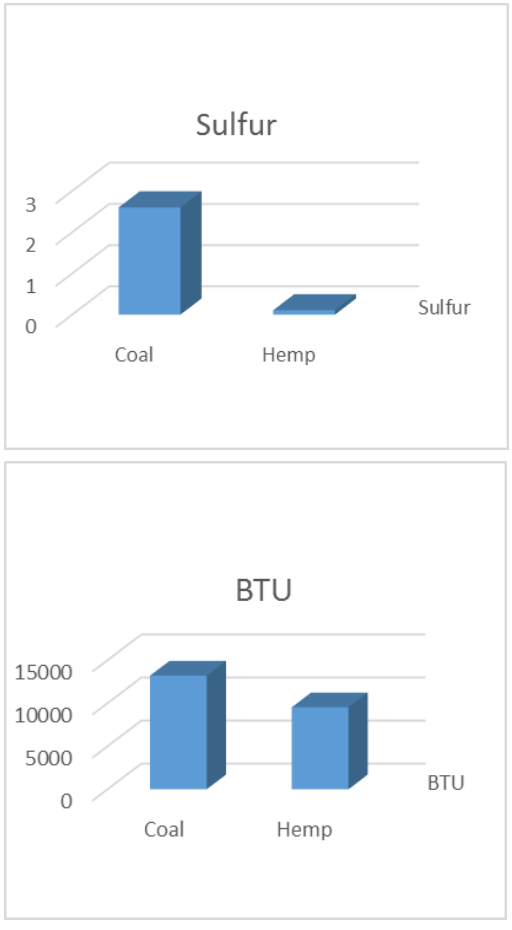

Figure 1. Comparison of energy content (BTU) and sulfur emissions (lb sulfur/ million BTU) obtained for test samples.

Technical Feasibility

A representative coal sample from the Illinois Coal Basin was obtained for determination of cogeneration thermal capacity and to determine the level of emissions reductions due to blending coal with hemp biomass. Analyses were done according to recognized global standards[69]. As is typical of coal from Appalachia with sulfur content of 3.45%, the coal was used to prepare a series of blended samples for combustion analysis. Testing of a series of co-blended samples was done to understand the impact of increasing the ratio of hemp to coal on energy yield and sulfur emissions. The results are shown in Figure 1.

Combustion of the hemp sample yielded 0.10 percent sulfur and 9533 BTU, thus hemp emits only 0.105 pounds of sulfur per million BTUs produced. By comparison, combustion of the coal sample yielded 3.45 percent sulfur and 13210 BTU generated per pound, thus the coal sample emits roughly 2.6 pounds of sulfur per million BTUs produced, well above the levels set by new regulatory standards. A fifty percent blend of dry hemp hurds and coal will reduce the sulfur emissions of the plant to 1.56 pounds of sulfur per million BTUs - a reduction of forty percent - still above new federal levels but within reach of scrubbing technology available today[70].

Our results show that hemp biomass is a promising feedstock for power co-generation, a notion supported by recent engineering and techno-economic studies[71][72]. The introduction of industrial hemp as a biomass energy feedstock can improve the economics of co-firing due to adaptability, high per-acre yield, and potential to be grown on post-mining land and reclamation sites.

Conclusions and Recommendations

There is now a solid body of evidence supporting the use of hemp as a feedstock for energy production as well as manufacturing. Research efforts must therefore shift from proof-of-concept and characterization performed in academic and government laboratories around the world to applied science and engineering associated with private sector deployment and commercialization of technology. Our vision is that existing power plants will serve as hubs for integration of agriculture, energy conversion, and manufacturing in a new economy that benefits from the ability to convert biomass, and particularly hemp, into thousands of valuable products[73]. Favorable economics will be achieved through highly integrated sets of conversion technologies that utilize regionally available biomass and manufacture diverse products ranging from liquid fuel and biogas to fertilizer and animal feed. Research on new technology can be accelerated and engineering will be informed by interfacing with mature processes, such that economic and environmental benefits can be realized. Life cycle analysis and techno-economic assessment of specific engineering applications of hemp-based manufacturing, fuel production, and power generation must now be used on a case by case basis to provide necessary knowledge to aid in decision-making for farmers, researchers, and manufacturers, and investors. Agricultural economic models also provide insights on the expected returns of hemp to compare with expected returns of currently produced crops in the area, and help to identify feedstock issues and project costs and market options for hemp as a biomass crop. These evaluations are routinely undertaken by companies to inform the engineering of physical plant operations, and are anticipated by both the KHGCA and WVHGCA as critical steps in the business development pipeline for the hemp industry in Kentucky and West Virginia.

To stimulate the hemp economy, we recommend that policy makers take the following actions to move forward decisively:

- Prioritize, as a matter of urgency, applied research and development in the form of integrated energy demonstration projects across the region, and develop expertise in life cycle analysis and techno-economic assessments of new energy production and manufacturing processes.
- Provide economic incentives to attract new businesses to the region for biomass processing, manufacturing of fuels, chemicals, and materials from hemp.
- Accelerate the re-development of hemp farming, processing, and manufacturing by creating Ag-Tech hubs for the translation of science and engineering to practice. Shared facilities would allow growers and researchers to rapidly produce seed stocks and develop new strains

optimized for energy production, and to provide space and physical resources that enable local outreach and encourage entrepreneurship.

- Support the formation of a regional private-public consortium to create a *Roadmap for Hemp-Based Manufacturing and Energy Production in Rural Kentucky and Central Appalachia*, to serve as a clear path for federal policy makers and funding agencies such as the Departments of Energy (DOE) and Agriculture (USDA) to follow.

The energy sector must continuously adapt and use viable technologies that are best for Kentucky, West Virginia and our nation. The war on coal has taken its toll. We need to save and create jobs in Kentucky and West Virginia. This white paper poses an adaptive solution; hemp is indeed a viable option.

[1] Prade, T., Svensson, S.E., Andersson, A., Mattsson, J. (2011) Biomass and energy yield of industrial hemp grown for biogas and solid fuel. *Biomass and Bioenergy*, 35 (7): 3040–3049. http://dx.doi.org/10.1016/j.biombioe.2011.04.006

[2] U.S. Energy Information Administration (2013, November 22). *Today in Energy*. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=13911.

[3] Ernst & Young (2013). *U.S. Coal Exports: National and State Economic Contributions*, prepared for the National Mining Association. Retrieved from http://www.nma.org/pdf/coal_export_report.pdf.

[4] Kentucky Department for Energy Development & Independence (2012). *Energy Profile*. Retrieved from http://energy.ky.gov/Documents/2012%20Kentucky%20Energy%20Profile.pdf.

[5] Cleetus, R., et al. (2012). Ripe for Retirement: *The Case for Closing America's Costliest Coal Plants*. Union of Concerned Scientists Publ. Retrieved from http://www.ucsusa.org/assets/documents/clean_energy/Ripe-for-Retirement-Full-Report.pdf.

[6] Johnson, K., and Tracy, T. (2013, September 11). "EPA Plan to Curb New Coal-Fired Power Plants," *The Wall Street Journal*. http://online.wsj.com/news/articles/SB10001424127887323864604579069550916021262.

[7] Blackford, L. (2013, September 20). "University of Kentucky gets $3.5 million for carbon-capture research," *Lexington Herald-Leader*. http://www.kentucky.com/2013/09/30/2852159/university-of-kentucky-gets-35.html.

[8] U.S. Department of Energy (2011). *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*. Retrieved from www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf.

[9] U.S. Department of Energy (2008). *I-65: America's First BioFuels Corridor*. Retrieved from http://www1.eere.energy.gov/bioenergy/pdfs/howe_20080501_timeline_map.pdf

[10] Renewable Fuels Association (2013). *Ethanol Facilities: Capacity by State and Plant*. Retrieved from http://www.neo.ne.gov/statshtml/122.htm.

[11] Biodiesel Magazine (2013). *List of Biodiesel Plants in the USA*. Retrieved from http://biodieselmagazine.com/plants/listplants/USA/.

[12] DuPont (2012). *Annual Review*. Retrieved from http://investors.dupont.com/phoenix.zhtml?c=73320&p=irol-reportsannual.

[13] Blanch, H.W., Adams, P. D., Andrews-Cramer, K. M., Frommer, W. B., Simmons, B. A., and Keasling, J. D. (2008). Addressing the need for alternative transportation fuels: the Joint BioEnergy Institute. *ACS Chem. Biol.* **3**:17-20.

[14] DOE Bioenergy Research Centers. Retrieved from http://genomicscience.energy.gov/centers/.

[15] Naik, S.N., Vaibhav, Goud, V., Prasant, Rout, K., Ajay, Dalai, K. (2010). Production of first and second generation biofuels: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 14(2): 578-597. http://dx.doi.org/10.1016/j.rser.2009.10.003.

[16] Murphy D.J. (2012). Oil crops as potential sources of biofuels. In Gupta, S.K. (Ed.), *Technological Innovations in Major World Oil Crops* (pp. 269-284). New York, NY: Springer.

[17] Saif M., Rehman, U., Rashid, N., Saif, A.,Mahmood, T., Han,J.-I.(2013). Potential of bioenergy production from industrial hemp (*Cannabis sativa*): Pakistan perspective. *Renewable and Sustainable Energy Reviews*, 18: 154-164. http://dx.doi.org/10.1016/j.rser.2012.10.019.

[18] European Commission (2009*). Energy from field energy crops – a handbook for energy producers.* Retrieved from http://www.encrop.net/.

[19] Castleman T. (2006) *Hemp biomass for energy*. Fuel and Fiber Company, Sacramento, CA.

[20] Poisa, L., and Adamovics, A.(2011). Evaluate of hemp (Cannabis Sativa L.) quality parameters for bioenergy production. *Proceedings from the Conference on Engineering for Rural development*.

[21] Burczyk, H., Grabowska, L., Kolodziej, J., Strybem M.(2008). Industrial hemp as a raw material for energy production. *J Ind Hemp,* 13(1):37-48.

[22] U.S. Department of Energy (2005). *Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion-Ton Annual Supply*. Retrieved from http://www1.eere.energy.gov/bioenergy/pdfs/final_billionton_vision_report2.pdf.

[23] Finnan, J., Styles, D. (2013). Hemp: A more sustainable annual energy crop for climate and energy policy. *Energy Policy*: 58: 152-162. http://dx.doi.org/10.1016/j.enpol.2013.02.046.

[24] Global Bioenergy Partnership (GBEP), Secretariat
Food and Agriculture Organization of the United Nations (FAO) Environment, Climate Change and Bioenergy Division, *A Review of the Current State of Bioenergy Development in G8 +5 Countries*. Retrieved from www.globalbioenergy.org.

[25] Manitoba Agriculture (2008). *National Industrial Hemp Strategy*, prepared for Food and Rural Initiative Agriculture and Agri-Food Canada. Retrieved from http://www.votehemp.com/PDF/National_Industrial_Hemp_Strategy_Final_Complete2.pdf.

[26] Rice, B.(2008). Hemp as a feedstock for biomass-to-energy conversion. Journal of Industrial Hemp, 13(2):145e56.

[27] Yang, R., Liu, G., Xu,., Li, M., Zhang,J., Hao, X. (2011). Surface texture, chemistry and adsorption properties of acid blue 9 of hemp (*Cannabis sativa L.*) bast-based activated carbon fibers prepared by phosphoric acid activation. *Biomass and Bioenergy*, 35 (1): 437-445. http://dx.doi.org/10.1016/j.biombioe.2010.08.061.

[28] Sung, Y.J., Shin, S.-J. (2011). Compositional changes in industrial hemp biomass (*Cannabis sativa L.*) induced by electron beam irradiation Pretreatment. *Biomass and Bioenergy*: 35 (7): 3267-3270. http://dx.doi.org/10.1016/j.biombioe.2011.04.011.

[29] Godin, B., Lamaudière, S., Agneessens, R., Schmit, T., Goffart, J.-P., Stilmant, D., A. Gerin, G., Delcarte, J. (2013). Chemical characteristics and biofuel potential of several vegetal biomasses grown under a wide range of environmental conditions. *Industrial Crops and Products*, 48: 1-12. http://dx.doi.org/10.1016/j.indcrop.2013.04.007.

[30] Kabir, M.M., Wang, H., Lau, K.T., Cardona, F. (2013). Effects of chemical treatments on hemp fibre structure, *Applied Surface Science*, 276: 13-23. http://dx.doi.org/10.1016/j.apsusc.2013.02.086.

[31] Kamireddy, S.R., Li,J., Abbina, S., Berti, M., Tucker, M., Ji, Y. (2013). Converting forage sorghum and sunn hemp into biofuels through dilute acid pretreatment. *Industrial Crops and Products*, 49: 598-609. http://dx.doi.org/10.1016/j.indcrop.2013.06.018.

[32] Abraham, R.E., Barrow, C.J., Puri, M. (2013). Relationship to reducing sugar production and scanning electron microscope structure to pretreated hemp hurd biomass (*Cannabis sativa*). *Biomass and Bioenergy*, 58: 180-187. http://dx.doi.org/10.1016/j.biombioe.2013.06.006.

[33] Sipos, B., Kreuger, E., Svensson, S.-E.,Réczey, K., Björnsson, L., Zacchi, G. (2010). Steam pretreatment of dry and ensiled industrial hemp for ethanol production. *Biomass and Bioenergy*: 34 (12): 1721-1731. http://dx.doi.org/10.1016/j.biombioe.2010.07.003.

[34] Pakarinen, A., Zhang, J., Brock, T., Maijala, P., Viikari, L. (2011). Enzymatic accessibility of fiber hemp is enhanced by enzymatic or chemical removal of pectin. *Bioresource Technology*, 107: 275-281. http://dx.doi.org/10.1016/j.biortech..12.101.

[35] Yang, R., Su, M., Li, M., Zhang, J., Hao, X., Zhang, H. (2010). One-pot process combining transesterification and selective hydrogenation for biodiesel production from starting material of high degree of unsaturation. *Bioresource Technology*, 101(15):5903-9. doi: 10.1016/j.biortech.2010.02.095. Yang R, Su M, Li M, Zhang J, Hao X, Zhang H.

[36] Ragit, S.S., Mohapatra, S.K., Gill, P., Kundu, K. (2011). Brown hemp methyl ester: Transesterification process and evaluation of fuel propertie. *Biomass and Bioenergy*, 41: 14-20. http://dx.doi.org/10.1016/j.biombioe..12.026.

[37] Moxley, G., Zhu,Z., and Zhang, Y.-H.P.(2008). Efficient Sugar Release by the Cellulose Solvent-Based Lignocellulose Fractionation Technology and Enzymatic Cellulose Hydrolysis. *Journal of Agricultural and Food Chemistry*, 56 (17):7885-7890.

[38] Lopez, J.P., Vilaseca, F., Barberà, L., Bayer, R.J., Pèlach, M.A., Mutjé, P. (2012). Processing and properties of biodegradable composites based on Mater-Bi® and hemp core fibres. *Resources, Conservation and Recycling,* 59: 38-42. http://dx.doi.org/10.1016/j.resconrec.2011.06.006.

[39] Balčiūnas, G., Vėjelis,S., Vaitkus, S., Kairytė, A. (2013). Physical Properties and Structure of Composite Made by Using Hemp Hurds and Different Binding Materials. *Procedia Engineering*, 57: 159-166. http://dx.doi.org/10.1016/j.proeng.2013.04.023.

[40] Yin, S. W.; Tang, C. H.; Wen, Q. B.; Yang, X. Q. (2007). Properties of cast films from hemp (*Cannabis sativa L.*) and soy protein isolates. A comparative study. *J. Agric. Food Chem.*, 2007, 55 (18): 7399–7404.

[41] Lu, N., Bhogaiah,S., Ferguson, I. (2012). Effect of alkali and silane treatment on the thermal stability of hemp fibers as reinforcement in composite structures, *Advanced Materials Research,* 415-417: 666-670.

[42] La Rosa, A.D., Cozzo, G., Latteri, A., Recca, A., Björklund, A., Parrinello, E., Cicala, G. (2013). Life cycle assessment of a novel hybrid glass-hemp/thermoset composite. *Journal of Cleaner Production*, 44: 69-76. http://dx.doi.org/10.1016/j.jclepro.2012.11.038.

[43] Li,Z., Cui,K., Tan, X, Stephenson, T.J., King'ondu, C.K., Holt, C.M.B., Olsen, B.C., Tak, J.K., Harfield, D., Anyia, A.O., and Mitlin, D. (2013). Interconnected carbon nanosheets derived from hemp for ultrafast supercapacitors with high energy. *ACS Nano* 7 (6), 5131-5141.

[44] Casas, X.A., Rieradevall, I., Pons, J. (2005). Environmental analysis of the energy use of hemp: analysis of the comparative life cycle: diesel oil vs. hemp diesel. *Int. J. Agric. Res. Gov. Ecol.*, 4(2):133-139.

[45] Ip, K., Miller, A. (2012) Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK. Resources, Conservation and Recycling, Volume 69, December, Pages 1-9, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2012.09.001.

[46] van der Werf, H.M.G., Mathijssen, E.W.J.M., Haverkort, A.J. (1996). The potential of hemp (*Cannabis sativa L.*) for sustainable fibre production: a crop physiological appraisal. *Ann. Appl. Biol.*, 129(1):109-123.

[47] Blouw, S., Sotana, M. (2007). Performance of four European hemp cultivars cultivated under different agronomic conditions in the Eastern Cape Province, South Africa. In Anadjiwala, R., Hunter, L., Kozlowski, R., Zaikov, G. (Eds.), *Textiles for Sustainable Development (pp. 3-11)*. Nova Science Publishers Inc.

[48] Di Bari, V., Campi, P., Colucci, R., Mastrorilli, M. (2004). Potential productivity of fibre hemp in southern Europe. *Euphytica*, 140(1-2):25-32.

[49] Deleuran, L.C., Flengmark, P.K. (2005). Yield potential of hemp (*Cannabis sativa L.*) cultivars in Denmark. *J. Ind. Hemp*, 10(2):19-31.

[50] Alaru, M., Kukk, K., Astover, A., Lauk, R., Shanskiy, M., Loit, E. (2013). An agro-economic analysis of briquette production from fibre hemp and energy sunflower. *Industrial Crops and Products*, 51:186-193. http://dx.doi.org/10.1016/j.indcrop.2013.08.066.

[51] Plochl, M., Heiermann, M., Linke, B., Schelle, H. (2009). Biogas crops part II: balance of greenhouse gas emissions and energy from using field crops for anaerobic digestion. *Agric. Eng. Int.,* XI:1-11.

[52] González-García, S., Moreira, M.T., Feijoo, G. (2010). Comparative environmental performance of lignocellulosic ethanol from different feedstocks. *Renewable and Sustainable Energy Reviews*, 14(7): 2077-2085. http://dx.doi.org/10.1016/j.rser.2010.03.035.

[53] Pretot, S., Collet, F., Garnier, C. (2014). Life cycle assessment of a hemp concrete wall: Impact of thickness and coating. *Building and Environment*, 72:223-231, http://dx.doi.org/10.1016/j.buildenv.2013.11.010.

[54] Brodersen, C., Drescher, K., McNamara, K. (2002). Energy from hemp? Analysis of the competitiveness of hemp using a geographical information system. In van Ierlund, E.C., Oude Lansink, A. (Eds.), *Economics of Sustainable Energy in Agriculture* (pp. 121-134), Kluwer Academic Publishers; Secaucus, USA.

[55] Alden, D.M., Proops, J.L.R., Gay, P.W. (1998). Industrial hemp's double dividend: a study for the USA. *Ecological Economics*, 25(3):291-301. http://dx.doi.org/10.1016/S0921-8009(97)00040-2.

[56] Kreuger, E., Sipos,B., Zacchi, G., Svensson,S.-E., Björnsson, L. (2011). Bioconversion of industrial hemp to ethanol and methane: The benefits of steam pretreatment and co-production. *Bioresource Technology*, 102(3): 3457-3465. http://dx.doi.org/10.1016/j.biortech.2010.10.126.

[57] McMahon, J. (January, 2008). Densified Biomass for Cofired Energy Generation, *Biomass Magazine*. Retrieved from http://biomassmagazine.com/articles/1403/densified-biomass-for-cofired-energy-generation.

[58] U.S. Department of Energy, by the National Renewable Energy Lab (2000). *Biomass Cofiring: A Renewable Alternative for Utilities*. Retrieved from http://www.nrel.gov/docs/fy00osti/28009.pdf.

[59] van Loo, S. and Koppejan, J., Eds. (2008). *The Handbook of Biomass Combustion and Co-firing*, Earthscan Publ., London, Sterling, VA.

[60] Prins, M.J., Krzysztof, J., Ptasinski, F., Janssen, J.J.G. (2006). More efficient biomass gasification via torrefaction. *Energy*, 31(1):3458-3470. http://dx.doi.org/10.1016/j.energy.2006.03.008.

[61] Schütt, F., Westereng,B., Horn, S.J., Puls, J., Saake, B. (2012). Steam refining as an alternative to steam explosion. *Bioresource Technology*, 111:476-481. http://dx.doi.org/10.1016/j.biortech.2012.02.011.

[62] Nykter, M., Kymäläinen, H.-R., Thomsen, A.B., Lilholt, H., Koponen, H., Sjöberg, A.-M., Thygesen, A. (2008). Effects of thermal and enzymatic treatments and harvesting time on the microbial quality and chemical composition of fibre hemp (*Cannabis sativa L.*). *Biomass and Bioenergy*, 32(5):392-399. http://dx.doi.org/10.1016/j.biombioe.2007.10.015.

[63] Garcia, C., Jaldon, Dupeyre, D., Vignon, M.R. (1998). Fibres from semi-retted hemp bundles by steam explosion treatment. *Biomass and Bioenergy*, 14(3):251-260. http://dx.doi.org/10.1016/S0961-9534(97)10039-3.

[64] Ling-Ping Xiao, Zheng-Jun Shi, Feng Xu, Run-Cang Sun, Hydrothermal carbonization of lignocellulosic biomass, Bioresource Technology, Volume 118, August 2012, Pages 619-623, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2012.05.060.

[65] Zhengang Liu, Augustine Quek, R. Balasubramanian, Preparation and characterization of fuel pellets from woody biomass, agro-residues and their corresponding hydrochars, Applied Energy, Volume 113, January 2014, Pages 1315-1322, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2013.08.087.

[66] Wenming Hao, Eva Björkman, Malte Lilliestråle, Niklas Hedin, Activated carbons prepared from hydrothermally carbonized waste biomass used as adsorbents for CO2, Applied Energy, Volume 112, December 2013, Pages 526-532, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2013.02.028.

[67] Zhengang Liu, Rajasekhar Balasubramanian, Upgrading of waste biomass by hydrothermal carbonization (HTC) and low temperature pyrolysis (LTP): A comparative evaluation, Applied Energy, Volume 114, February 2014, Pages 857-864, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2013.06.027.

[68] Zimmerling, S., (2013). *"Torrefied / Refined Pellets for Biomass Co-Firing"* (White Paper). VGB PowerTech e.V., the European trade association for electricity and heat. Retrieved from http://www.vgb.org/vgbmultimedia/Fachgremien/Erneuerbare/White_Paper_torrefied_refined_fuels_for_biomass_co_firing_2013_05-p-6826.pdf.

[69] ASTM Standard D7582, 2011, " Standard Test Methods for Proximate Analysis of Coal and Coke by Macro Thermogravimetric Analysis," ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03, www.astm.org. http://www.astm.org/Standards/D7582.htm.

[70] U.S. Energy information Administration (February, 2013). Power plant emissions of sulfur dioxide and nitrogen oxides continue to decline in 2012. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=10151.

[71] De, S., Assadi, M. (2009). Impact of cofiring biomass with coal in power plants – A techno-economic assessment. *Biomass and Bioenergy*, 33(2):283-293. http://dx.doi.org/10.1016/j.biombioe.2008.07.005.

[72] Sami, M., Annamalai, K., Wooldridge, M. (2001). Co-firing of coal and biomass fuel blends. Progress in Energy and Combustion Science, 27: 171-214.

[73] Barta, Z., Kreuger, E., Björnsson, L. (2013). Effects of steam pretreatment and co-production with ethanol on the energy efficiency and process economics of combined biogas, heat and electricity production from industrial hemp. *Biotechnol Biofuels*, 6(1):56. doi: 10.1186/1754-6834-6-56.