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INSTITUTE OF TROPICS AND SUBTROPICS

MASTER THESIS

Energy balance of hemp grown for energy purposes

Bc. Michel Krejčová
Prof.Ing. Bohumil Havrland, Csc.

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Declaration

I hereby declare that I have written presented bachelor thesis “Energy balance of hemp grown for energy purposes” by myself with help of the literature listed in references.

Prague, 15 April 2012

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Michel Krejčová

Acknowledgement

I would like to sincerely thank to Professor Bohumil Havrland for valuable advance, consultation, space and confidence, to Ms. Tanja Ivanova, Msc and Mr. Josef Pecen, associate professor, for their assistance; to my husband for his absolute support and to my employer for tolerance.

ABSTRACT

Master thesis entitled “Energy balance of hemp grown for energy purposes” discusses autumn and spring harvest of hemp biomass to make solid biofuels –briquettes. The hemp plant (Cannabis sativa L.), variety of Polish origin – Bialobrzeskie, was sown on a trial plot in the Suchdol district of Prague in May 2009 and June 2011. The first one was harvested in autumn (October), second part was harvested in spring (March). Its samples were subjected to experiments during which humidity contents, calorific value and other technical parameters were determined. Biomass was used for solid biofuels production. Autumn harvest produced 24.3 t/ha of green and 10.93 t/ha of dry biomass. GCV measured in adiabatic calorimeter MS110 was 17.04 GJ/t, which determined that the gross energy yield of dry matter was 186.28 GJ/ha. Spring harvest in March 2012 produced a 31% decreased biomass yield with a moisture content of 19.09% and its GCV at a level of 19.31 GJ/t. The determined gross energy yield for this kind of harvest was 145.59 GJ/ha.

An integral part of the commodity balance was a calculation of inputs for individual technological operations. Autumn harvest total inputs (22.154 GJ/ha) represented 11.8% of outputs. Spring harvest sum of energy inputs (16.849 GJ/ha) made 11.5% of total produced energy. Autumn share of direct inputs (labor force, energy in fuels) and indirect inputs (energy embodied in machines, energy in fertilizers and energy in seeds) were 49.99% (1.07%, 98.93%), and 50.01% (8.62%, 91.38%), respectively. Spring harvest consisted of 34.2% of direct energy (labor, fuels) and 65.8% indirect energy; individual items of inputs: energy in fertilizers (8,753 MJ/ha), fossil energy (5,663 MJ/ha), energy in seeds (1,371 MJ/ha), energy in machines (960 MJ/ha) and energy of human labor (104 MJ/ha) which represent: 51.95%, 33.61%, 8.14%, 5.7%, and 0.62%, respectively. The main share on inputs contributes fossil energy for autumn harvest and products of chemical industry for spring harvest. Regardless higher energy gain in autumn (164.13GJ) compared with spring (128.74 GJ/ha), it was found that for the conditions listed in the Thesis spring harvest should be preferred because its energy efficiency (EROEI = 8.64) is higher as compared with autumn harvest (EROEI = 8.41).

Key words: hemp (Cannabis sativa), energy balance, energy input, energy output, yield, GCV, EROEI

ABSTRAKT

Diplomová práce nazvaná "Energetická bilance konopí pěstovaného pro energetické účely" pojednává o podzimní a jarní sklizni konopné biomasy k výrobě pevných biopaliv- briket. Konopí seté (Cannabis sativa L.), polská podrida Bialobrzeskie, byla vyseta na pokusném pozemku v Praze-Suchdole v květnu 2009 a červnu 2011. První z nich byla sklízená na podzim (říjen), druhá část byla sklizena na jaře (březen). Vzorky konopných stonků byly podrobeny zkouškám, během nichž byly stanoveny obsah vlhkosti, spalné teplo a další technické parametry. Biomasa byla použita pro produkci pevných biopaliv. Podzimní úroda vyprodukovala 24.3 t/ha nadzemní biomasy a 10.93 t/ha sušiny. Spalné teplo, měřené v adiabatickém kalorimetru MS110, bylo 17.04 GJ/t, které determinovalo hrubý energetický zisk ve výši 186.28 GJ/ha. Při jarní sklizni došlo k úbytku výnosu biomasy o 31%; vlhkost rostlin konopí dosahovala 19%, spalné teplo 19.31MJ/ha, což určilo hrubý energetický výnos pro tento druh sklizně 145.5 GJ/ha. Součástí komoditní bilance byla kalkulace energetických vstupů pro jednotlivé technologické operace. Vstupy podzimní sklizně (22.154 GJ/ha) představovaly 11.8% celkových energetických výstupů. Energetické vstupy jarní sklizně (16.849 GJ/ha) tvořily 11.5% získané energie. Podzimní podíl přímých vstupů (lidská práce, fosilní energie) a nepřímých vstupů (energie zhmotněná ve strojích, energie v hnojivech, energie v osivu) byl v tomoto pořadí: 49.99 % (1.07%, 98.93%), a 50.01% (8.62%, 91.38%). Jarní sklizeň se skládala z 34.2% přímé energie (práce, paliva) a 65.8% nepřímé energie; jednotlivé složky vstupů: energie v hnojivech (8,753 MJ/ha), fosilní energie (5,663 MJ/ha), energie v osivu (1,371 MJ/ha), energie ve strojích (960 MJ/ha) a energie lidské práce (104 MJ/ha), které představovaly: 51.95%, 33.61%, 8.14%, 5.7%, a 0.62%. Největší podíl na energetických vstupech měla fosilní energie pro podzimní sklizeň a hnojiva pro jarní sklizeň. Bez ohledu na energetický zisk podzimního výnosu (164.13 GJ/ha) ve srovnání s jarní ziskem (128.74 GJ/ha), bylo shledáno, že pro podmínky uvedené v této práci by měla být preferovaná jarní sklizeň, z důvodu vyšší energetické účinnosti (EROEI= 8.64) v porovnání s podzimní sklizní (EROEI= 8.41).

Klíčová slova: konopí (Cannabis sativa), energetická bilance, energetický vstup, energetický výstup, výnos, spané teplo, EROEI

Table of Contents

List of Abbreviations

BEY	Biomass energy yield
BY	Biomass Yield
CO_2	Carbon dioxide
DM	Dry Matter
EROEI	Energy Return On Energy Invested
EU	European Union
FAME	Fatty Acid Methyl Ester
FAO	Food and Agricultural Organization
FF	Fossil fuels
FMZŽv	Federální ministerstvo Zemědělství a Živočišné výroby
GCV	Gross Calorific Value
GHG	Greenhouse Gases
LCA	Life Cycle Assessment
MC	Moisture content
MDGs	Millennium Development Goals
ME	Ministry of Environment
MIT	Ministry of Industry and Trade
MZP	Ministerstvo životního prostředí (Ministry of Environment)
RES	Renewable energy source
THC	Tetrahydrocannabinol
UNSD	United Nations Statistical Databases
VÚRV	Výzkumný Ústav Rostlinné Výroby
VÚZEI	Výzkumný Ústav Zemědělské Ekonomiky a Informací
VÚZT	Výzkumný Ústav Zemědělské Techniky

Technical notes

Basin unit and element of energy is 1J.

1 joule (J) is the amount of mechanical energy required to displace a mass of 1 kg through a distance of 1 m with an acceleration of 1 m per second ($1 J = 1 kg \times 1 m^2 \times 1 sec^{-2}$). Multiples of 1 000 (kilojoules, kJ) or 1 million (megajoules, MJ) are used in human nutrition. The conversion factors between joules and calories are: 1 kcal = 4.184 kJ, or conversely, 1 kJ = 0.239 kcal.

$PJ = 10^{15} J$

$EJ = 10^{18} J$

List of Tables

List of Figures

1. INTRODUCTION

The effort of the most developed countries to use fossil fuels efficiently and as far as possible its replacement by renewable sources of energy, scientific research heads toward testing energy crops (whose potential is the highest of RES) and focus primarily on their energy balance. Hemp (Cannabis sativa), a plant prohibited over the world for years for its psychoactive terpenoids, has been experiencing a worldwide revival. A crop that is currently grown mainly for very resistant fiber, is also unique in its composition, which from the energy point of view, is endowed hardly by any crop. It can be used as source of solid biofuels (briquettes, pellets), a source of biomass for biogas plants with production of methane, the lignocellulosic composition includes cannabis among secondary generation crops for ethanol production. Finally let us mention cannabis seeds, which can be used in energy terms to produce biodiesel. Industrial hemp is well known for its yield potential and gross calorific value, comparable with wood. The uniqueness of this plant lies in its ability to create over 24t of biomass per hectare during 120 days.

This work is conceived as literature review and practical part. The first chapters are devoted to the issue of renewable sources of energy and to energy crops. The literature review provides information about current scientific research on cannabis use for energy purposes. Energy balance, its history and importance especially in agriculture are also mentioned.

A practical part of this thesis builds on the bachelor thesis “Testing energy crops-industrial hemp” and expands knowledge about its more difficult and not easy calculated part -energy inputs. Advantages and its drawbacks are mentioned in the discussion. At the end of the thesis there are outlined recommendations for opportunities for further scientific survey in the area of hemp utilization for energy.

2. LITERATURE REVIEW

2.1 Renewable energy

By signing The Kyoto protocol[1] the Czech Republic has undertaken the task to reduce emissions of greenhouse gases[2] by 5.2% over the period of 2008-2012 (compared to 1990). Although the CR is successful in achieving targets for reducing emissions, when its goal for the share of energy produced from RES in the total consumption of primary energy sources in 2010 at 6% was fulfilled, more efficient scale - the amount of CO2 per capita is still very high (ME, 2009).

See the map of CO2 emissions per capita in the world (Figure 1). The Czech Republic is marked in the map by dark red with 11.5 tons of CO2 per capita.

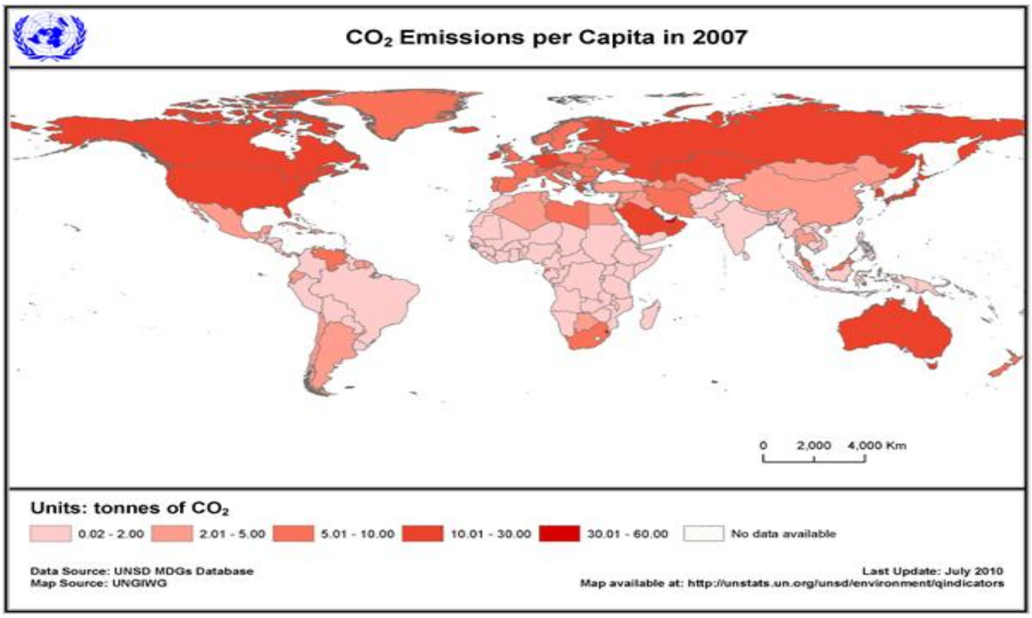

Figure 1 Co2 emission per capita in 2007

Source: United Nations (2010)

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[1] The Kyoto protocol is a protocol to the United Nations Framework Convention on Climate Change with the aim to stabilize the concentration of GHG in the atmosphere. The Protocol was initially adopted on 11 December 1997 in Kyoto, Japan, and entered into force on 16 February 2005. As of September 2011, 191 states have signed and ratified the protocol.

[2] GHG (Greenhouse gases) - carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulphur hexafluoride (SF6), hydro fluorocarbons (HFCs)and per fluorocarbons (PFC)

The mitigation of global warming and its consequences could be possible through several different scenarios: by reducing energy intensity, by increasing energy effectivness, by changing fuels with a lower production of carbon dioxide (change in the structure of energy resources (ME, 2009).

Table 1: Share on energy consumption in CR

Share on energy consumption (CR)	2000	2030
Solid fuels:	52,4 %	30,5 %
- brown coal	36,6 %	20,8 %
- black coal	15,8 %	9,7 %
Gaseous fuels	18,9 %	20,6 %
Liquid fuels	18,6 %	11,9 %
Nuclear fuels	8,9 %	20,9 %
Renewable sources	2,6 %	15,7 %

Source: MPO (2009)

The Czech Republic does not have many raw material resources; most mineral materials are imported (petroleum -100% imports). The country's stocks of some mineral resources have been exhausted. According to Nation Communication Report of the Ministry of Environment, this country consumes more primary energy sources and electricity than necessary so that consumed energy is inadequately converted to added value (ME, 2009).

The use of traditional sources of energy is cheap, and to some extent available. It does not depend on natural conditions and accumulates large amounts of energy per unit. Those are the main advantages. Nevertheless all fossil fuels (FF) release carbon dioxide when burned which causes global warming. Burning coal and oil produces toxic pollutants that result in smog, air pollution, lung diseases and acid rain. Import of FF is closely related to dependence of unstable economies. FF will be exhausted soon, so this country needs an alternative solution (ME, 2009).

The largest share of energy from renewable sources in 2009 was occupied by biomass: 42.01% biomass - households and 30.83% biomass - non-household, together biomass accounted for 72.84% of total energy from renewable sources. For the other RES, the share of total energy from renewable sources came from hydropower 8.45%, for liquid biofuels and biogas 7.13%, 5.26%, respectively. The remaining approximately

6.3% was attributable to heat pumps, bio-biodegradable portion of industrial waste, wind power and solar energy (MZe, 2010).

2.2 Biomass energy

Bioenergy is obtained from biomass[3] including plants, animals and microorganisms. Most bioenergy is used in rural areas (especially in third world countries), where traditional wood for heating and cooking has been preferred. Prade (2011) estimates that global primary energy consumption is at level of 10-14%.

This thesis deals with biomass utilization for commercial energy production which can be separated into two groups:
1. Residues
2. Biomass cultivated for sole purpose

The situation in the Czech Republic according to Green note (2010) is the following: Energy use of biomass for electricity and heat energy is mainly in the form of co-combustion of wood (including pulp extracts) and plant matter (especially in larger power plants), and also in the production of biogas. In 2009 burning biomass produced 1,596 GWh of electricity by burning biomass. The proportion of briquettes and pellets of plant materials rose to 8.8% to 94,000 tons. The production of heat energy from biomass (excluding households) in 2009 reached 15,498 TJ. By far the largest share of consumed fuel (biomass) was attributable to wood waste, sawdust, bark, wood chips and forest residues (51.1% share of utilized biomass) and cellulose extracts (43.6%).

In the Czech Republic anaerobic digestion as a part of municipal wastewater treatment technology has been traditionally used on a wide scale. The constructions of new biogas plants are currently enjoying a boom. According to statistics from MIT in 2009 a total 259.6 million m3 of biogas was used for energy purposes (MPO, 2009).

Legislation regulates the use of biofuels in the Czech Republic and how they must blend with mineral fuels. This obligation was introduced for the first time in September 2007 for the addition of FAME[4] in diesel (2% by volume), in 2008 for the addition of bioethanol to gasoline as well. From 2010 it became compulsory to increase the percentage of FAME in diesel from 4.5% to 6%, and from 3.5% to 4.1% for the addition of ethanol into gasoline. The main sources for bioethanol production in the Czech Republic are sugar beet, wheat and maize with total production of 292,000 t. FAME is produced from rapeseed oil mostly, with volume 52,100 t (MZe, 2010)

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[3] organic materials of living or recently living organisms

[4] FAME = fatty acid methyl ester, used as biodiesel vehicle fuel

Table 2: Biomass conversion processes

Process	Conditions	Energy carriers
Gasification	Thermal conversion/limited air/ oxygen supply	Syngas
Pyrolysis	Thermal conversion/exclusion of air/oxygen	Char, pyrolysis, oil, syngas
Torre fraction	Thermal conversion/exclusion of air/oxygen	Char
Transesterification	Chemical conversion	Oils (FAME)
Fermentation	Biochemical conversion	Alcohols, acetone

Source: Prade (2011)

Bioenergy seems to be a widespead source of RES worlwide. Strong requirements for sustainability and higher interest in production from biomass result in a demand for high-yielding energy crops with good conversion efficiencies (Prade, 2011).

2.3 Energy crops

Energy crops, according to an EU definition, are plants with the following features: low cost, low maintenance harvest, densely planted, high yielding. They are used to make biofuels or combusted to generate electricity or heat. According to carbohydrate content they can be also converted into biogas (e.g. maize). Energy crops are divided into two groups: woody (e.g. poplar, willow) and herbaceous (e.g. Miscanthus, hemp).

In the EU-27 there are 111 mil hectares of arable land and 69 mil hectares of permanent grassland. The population of EU 27 is about 502,486,499 (EUROSTAT, 2011). Area needed for food production would be about 62% of arable land of this territory, if the diet is moderate which is mixed vegetable-animal product (Holm Nielsen et al., 2007 cited by ENCROP, 2009). According to ENCROP[5] results, EU is able to utilize 10-30% of arable land for energy crops cultivation. This would produce 2-6 EJ of bioenergy with an average yield of 10 tons of dry matter per hectare.

Energy crops currently contribute a relatively small proportion to the total energy produced from biomass each year, but their potential is great and their importance is still increasing. ENCROP project set by EU countries the centers around of interest reed canary grass, willow, hemp and poplar, focusing mainly on two pathways – direct combustion and conversion into biogas.

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[5] ENCROP – project of EU to promote the production and utilization of lignocelluloses energy crops in Europe.

Biomass produced from fields consists of residues (e.g. straws) and specially cultivated crops. Otherwise not all residues are available for bioenergy production. Part is used as livestock feed and litter; some have to remain to maintain soil fertility. In the EU-27 countries crop residues potential for bioenergy is estimated to be 1-3 EJ. The majority is accumulated in straw. The current leader in straw utilization for energy production is Denmark (ENCROP, 2009).

Some EC are limited to cultivation for their requirements, as Prade (2011) formulated in his thesis. For example, sugar cane (Saccharum officinarum) – is cultivated for bioethanol in Brazil, maize (Zea L.) is grown in the U.S. for bioethanol, soybean (Glycine max) produces biodiesel in USA, rapeseed (Brassica napus)-FAME in Europe (Germany, France), and Jatropha curcas (biodiesel in China and India).

The situation in the Czech Republic was outlined by Petříková et al. in 2006; the sown area of crops for energy use was 1,270 hectares, of which 1140 ha is for perennial and 130 ha for annual plants. Current data about cultivated area for energy purposes are not available. Growing herbal plants (for sole purpose of energy utilization) does not have tradition in our country. Most plants have been tested and verified, but a comprehensive guide does not exist. Petříková et al. (2006) also recommended for cultivation in the Czech Republic mainly plants from the table 3 according to experimental researches' results.

Table 3: Energy crops suitable for CR

Lignocelluloses' plants	Woody plants (willow, poplar, alder, acacias)
	Cereals (whole plants)
	Grass (elephant grass, Reed canary grass, permanent grasslands)
	Other plants (hemp, sorghum, knotweed, rumex, mallow, hollyhock)
Oil plants	Oilseed rape, sunflower, flax
Starch – sugar plants	Potatoes, sugar beet, corn grain, Jerusalem artichoke, maize

Source: Petříková et al. (2006)

Advantages of EC summarized from a lot of researches: (Petříková et al., 2006; Prade, 2011; Sladký, 2004)

- Composition and level of contamination is relatively well known and constant (compared with residues biomass)

- The deliberate cultivation of energy plants in anthropogenic soils or soils unsuitable for growing food leads to the revitalization of these soils

- Landscape maintenance and protection of soil erosion
- Enhance stability of small and medium enterprises in rural areas
- It also provides new job opportunities, which is very important in areas with high unemployment

2.4 Hemp (Cannabis sativa)

The Cannabis genus includes 3 species:

Cannabis Sativa (this thesis deals with this species)
Cannabis Indica (high content of THC[6], forbidden to grown)
Cannabis Ruderalis (weed)

The annual herbaceous crop Cannabis sativa (belongs to Cannabaceae family) has been grown for its fiber and seed for centuries. It originates in Western Asia and India. The first appearance of hemp in the Czech Republic was found in archaeological excavations in Modlešice (close to Rakovník). The excavations demonstrated the use of hemp stalks to seal wooden troughs used to capture gold-bearing sand in the Celtic La Tene period from the 4th century BC (Petříková et al., 2006).

Industrial hemp was a suitable source to produce materials such as paper, cloth and ropes. The seeds were used as human and animal food. In the past centuries, oil from hemp seeds was utilized for lighting. Nevertheless the import of cheap fiber material (jute from India and sisal from Central America) caused reduction in hemp production (Prade, 2011). Cannabis was grown around the world for the above mentioned purposes until the 1930s. After that there are several reasons why hemp cultivation went on decline. Synthetic fibers such as nylon[7] were developed, technologies for making paper

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[6] THC tetrahydrocannabinol- aromatic terpenoid, principal psychoactive substance produced naturally by plants.

[7] nylon – most commonly used and commercially successful synthetic polymer, first produced in 1935 in Wilmington.

from trees were improved and hemp in the form of marihuana[8] was labeled as an illicit drug (Hollebane, 1999). In 1937 in the U.S. cultivation of hemp was forbidden due to its psychotropic substances (THC) and later prohibition was spread to all countries. Prohibition is still in force in the U.S. and in Norway.

Cannabis sativa can be grown within the EU, but there are some restrictions for cannabis cultivation. In a case of production of hemp the varieties used shall have a tetrahydrocannabinol content not exceeding 0.2 %[9], only certified seeds of certain varieties can be used, and areas growing hemp require administrative approval (EU, 2003).

According to FAO, the area for total worldwide cultivation is 48,956 ha (FAO, 2012). The world's leading producer of hemp is China, which grows industrial hemp for its fibers on about 16,500 ha. There is smaller production in Europe, Chile and the Democratic People's Republic of Korea. In the European Union hemp is grown on around 15 000 ha of land. Major producers are France, Germany and the UK.

2.4.1 Botanical description

Hemp is a thermophilous plant that can be grown at higher altitudes (up to 5000 m) with correspond yield. Cannabis is a dioecious crop; compared with the females, male plants are more slender and mature earlier. For industrial utilization monoecious varieties are preferred, due to their uniform ripening (Sladký, 2004). Hemp can grow up to 5m in height. It is one of the most efficient plants known for its ability to utilize sunlight to photosynthesize (Hollebane, 1999).

Approximately 25-35% of stem dry matter is fiber (depends on variety). There are 3 kinds of fibers: primary bast (long and low in lignin), secondary bast (intermediate and high in lignin) and libriform (short and high in lignin) (Hollebane, 1999). See the layers of hemp stem on, where are described individual layers´ function and its real appearance.

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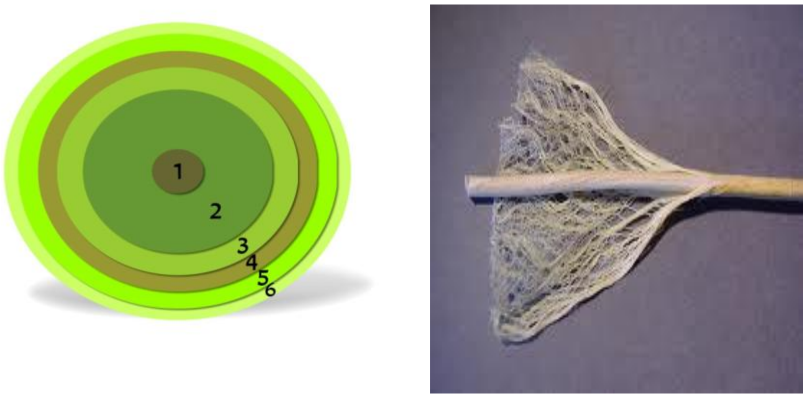
[8] marijuana is a plant of the same genus and species as industrial hemp, but has taken a different path of development over the years. Some marijuana varieties have over 25 % THC in specific parts of the plant.

[9] According to the Czech Republic and EU regulations growers of industrial hemp in this country have to analyze plants samples under Custom Service supervision. Samples come from upper crop part and from various places of plot. There is also necessary to report on cannabis sawing, in the middle of growing season (when flowering), harvesting and processing.



- 1 Hollow core
- 2 Pith layer (woody tissue, called hurds, 60-75% of total mass)
- 3 Cambium layer (growth area; produces hurds on side and bast and bark on outside, place where fiber and hurds are separated during the retting /breaking process)
- 4 Parenchyma layer (short cells containing chlorophyll + long cells –bast fibers)
- 5 Cortex layer (walled cells, no fiber, just chlorophyll content)
- 6 Epidermis layer (protection of plant cells)

Figure 2: Hemps ´stem layers

Source: HOLLEBANE, 1999

Leaves from plants harvested in autumn account for approx. 30% of the total plant biomass of hemp, while seeds account for approx. 1-10% in fiber hemp cultivars (Prade et al., 2011). Sladký (2004) stresses the high resistance of hemp against weeds and diseases.

2.4.2 Current research

Current research pays a special attention to utilize high biomass crops, especially for their fiber. Hundreds of tests try to develop suitable processes to obtain quality fiber. For example Chine, the world´s leader in hemp fiber production sees hemp´s future in cottonization to produce fine, soft textile fiber suitable for blending with cotton, wool and other synthetics (FAO, 2009).

In the last decade, experiments to use hemp for phytoremediation purposes were first done in the Czech Republic. Agritec, a research and cultivation institute has been trying to use hemp to capture heavy metals (lead and cadmium) from contaminated anthropogenic soils. Results of the survey are still incomplete and are not sufficient to apply for commercial use of the crop for large scale soil phytoremediation (Bjelková et al., 2005).

There are several mentions of hemp utilization for energy purposes in Canada, Ireland, Spain, Germany, Sweden, and Poland [Castleman, 2006; Burczyk et al., 2008; cited by Prade 2011]. Unfortunately current data are not available. From the literature only Prade has provided information about large- scale hemp growing for energy purposes in Sweden (800 ha) whereas all hemp biomass is processed into solid fuel (briquettes) for household heating (Prade, 2011).

Scientific experiments related to utilization of hemp for energy purposes are described in some chapters.

2.4.3 Possible pathways for utilization of hemp energy

In the table 4 below can be seen all possible uses of hemp for energy purposes. Firstly, the whole plant can be used as a source for solid biofuel. Secondly, the whole plant is also suitable material for biogas production (produces CH_4). Thirdly – hemp stems can be also used as source of bioethanol. The last possible utilization is biodiesel production from hemp seeds.

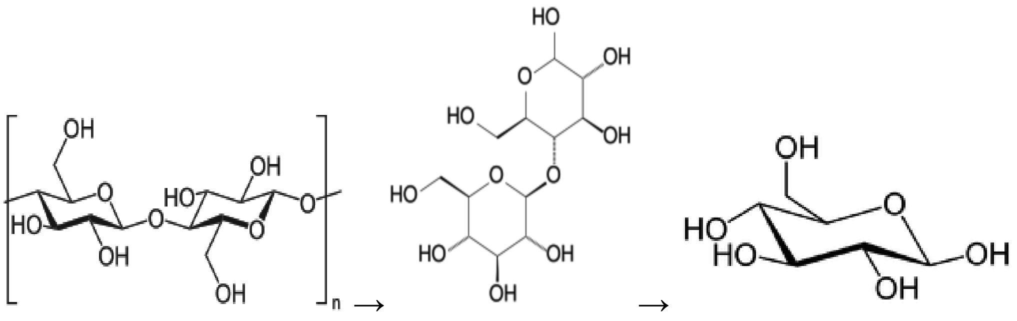
Table 4: Possible pathway of hemp utilization

Part of plant	Process	Product	Use
Whole plant	Anaerobic digestion	Biogas+ digestate	Vehicle fuel, heat and/or electricity Fertilizer/ solid fuel
Whole plant	Pelleting/ briquetting	Pellets/ briquettes	Heat and /or electricity
Whole plant	Saccharification +fermentation	Bioethanol	Vehicle fuel
Seeds	Processing+ transesterification	Biodiesel	Vehicle fuel

Source: Prade (2011)

2.4.3.1 Hemp as source of bioethanol

Conversion of hemp into bioethanol is done by fermentation. Fermentation is a process where cellulose is broken down into fermentable glucose using an acid catalyst or cellulose enzyme complex.



Cellulose -----------> cellobiose -------------> glucose

Figure 3: Degradation of cellulose into glucose

Estonian research scientists Tutt et al. (2011) bring new knowledge about the suitability of various plant species for ethanol production, including cannabis. Bioethanol is enjoying a rapid increase in production due to market demand (Tutt et al., 2011). They also wrote that bioethanol is currently becoming an attractive fuel for several reasons: it comes from renewable sources, it is oxygenated, and it has the potential for reducing engine emissions.

First generation biofuels used sugar substances and grain; their supply is limited and relatively expensive. These technologies still exist on a large scale (Barta et al., 2010). Barta also mentioned that utilization of lignocelluloses materials and sophisticated technologies to create second generation biofuels. Lignocelluloses' material is abundant, available and at a low cost. Lignocelluloses' feedstock contains cellulose, hemicelluloses and lignin.

Demirbas (2005) evaluated positively production of ethanol from cellulosic feedstock and its utilization as a substitute for gasoline, because it could promote rural development, reduce GHGs and achieve better energy independence.

Hemp hurds contain high cellulose content (53.86%), hemicelluloses (10.6%) and lignin 8.76% (Hinz, 1999). See the table 5 where Tutt et al. (2011) comparing different plants.

Table 5: Selected energy plant composition

Sample	Ash %	Hemi cellulose %	Cellulose %	Lignin %
Energy grass	7.01	27.33	37.85	9.65
Miscanthus sacch.	5.37	30.15	42.00	7.00
Sunflower	9.78	5.18	34.06	7.72
Helianthus tuberoses	5.15	5.48	20.95	5.05
Hemp	5.25	10.60	53.86	8.76
Silage	-	25.96	39.27	9.02
Reed	-	31.50	49.40	8.74

Source: Tutt et al. (2011)

Barta et al. (2010) finds Cannabis to be suitable because of high carbohydrate content. It has great potential to become a second generation biofuel.

Contemporary research is focused on suitable pre treatment methods. Barta at al used steam as an appropriate pretreatment of hemp hurds that was investigated for sugar and ethanol production by enzymatic hydrolysis and simultaneous saccharification and fermentation. The AFE method (Ammonia Fiber Expansion), which is commonly used, seems to harm the environment and not be cost effective.

The level of glucose yield was determined to be at 336 g /kg of dry hurds according to Barta et al. (2010) and 312.7 g/kg by Tutt et al. (2011). The highest ethanol yield was 141 g/kg of dry hurds (Barta et al., 2010).

2.4.3.2 Hemp as a biogas substrate

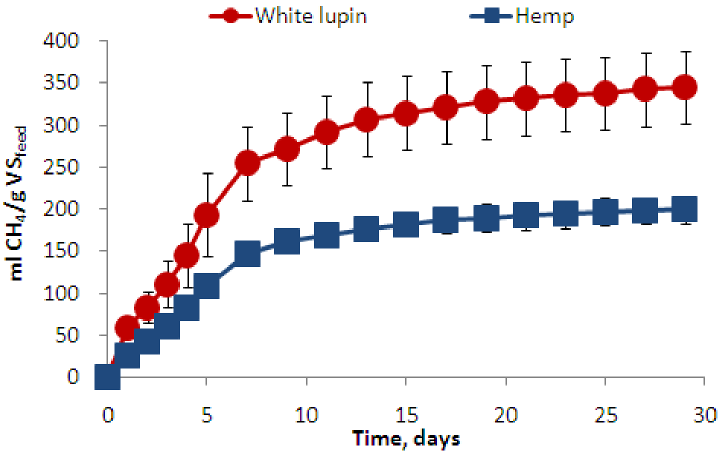
Energy crop suitability for biogasification must have a high biomass and biogas yield. Pakarinen, et al. (2010) point out the key role of lignin and polysaccharides (cellulose and hemicelluloses), their degradability and ability to hydrolyze. In the table 6 is seen composition of hemp in comparing with lupine. Biomass yields of the Finland experiment were 14 t/ha DM (hemp) and 18 t/ha DM (lupine).

Table 6: Hemp composition in comparison with lupine

Crop/ component	Glucan non-celulose	Glucan cellulose	Xylan	Arabian	Galactan	Mannan	al-A	Protein	Lignin
Hemp	4.3	33.8	4.8	1.3	1.7	1.6	5.3	9.1	1.4
Lupin	10.2	14.3	6.5	2.6	4.7	1.2	.9	16.9	6.2

Source: Pakarinen et al., 2010

In the graph (figure 4)we can see how methane yield depends on time during anaerobic digestion. Methane production in 30 days averaged about 345 and 200 ml/g VS feed for hemp and lupine, respectively. The methane productions were 26.2 (hemp) and 58.3 (lupine) MWh



Furthermore, KRAUGER et al. (2011) recognized that 34 day long termophylic digestion did not show significant differences among samples of different harvest times in the specific methane yield. But obviously there was a significant disparity in biomass yield (from 3.6 t/ha up to 14.3 t/ha for 146 day long growing season). According to Swedish research, the energy yield in the form of methane per hectare was highest in September (119 days after sowing) at a level of 122 GJ per hectare and in October (146 day long growing period) at a level of 111 GJ/ha. All of the above details are described in table 7. (Gross calorific value of methane: 35.9 MJ per Nm^3)

Table 7: Methane yield of hemp

Days after sowing	63 days	83 days	119 days	146 days
Nm^3 CH$_4$/kg	0.25	0.27	0.26	0.23
Ton/ha	3.6	6.9	14.2	14.3
GJ CH$_4$/ha	29	62	122	111

Source: Krauger et al. (2011)

2.4.3.3 Hemp as a solid fuel

There are several theoretical possibilities for the utilization of cannabis as solid biofuel. Whole hemp plants can be harvested either as a green plants in the autumn, or as a plant with low water content in early spring. Prade (2011) in his doctoral thesis mentioned, that digestate from biogas station also can be processed for solid fuel. Otherwise he refers high moister content therefore digestate is better as fertilizer (Prade, 2011).

Some of the companies engaged in hemp cultivation for fiber are trying to use hemp shives (by-product after decortications) for production of pellets or briquettes. From an economic and market perspective it is more advantageous to produce other products.

Figure 5: Pellets, briquettes and hurd made of hemp,

Source: Sladký (2004)

Autumn harvest occurs in late September or early October, when the water content of crops is approximately 55-74%. Crops can be left to dry during winter in warehouses, but free suitable space is necessary. Another way of lowering moisture is by drying using agricultural drying machines. This kind of yield is higher due to leaves and seeds (Prade et al., 2011; Sladký, 2004).

Just one scientific study about yield and the consequences of moisture content exist. Strašil (2005) compared several plants from autumn and spring harvests. The table below shows his experiment results (Strašil, 2005).

Prade et al. (2011) evaluated the physical and chemical properties of solid fytofuels. They mentioned that those attributes influence its suitability and subsequent competetiveness among solid biofuels. However physical properties[10] can be changed by physical treatment (milling, etc.); chemical properties[11] are hard to change once the crop is harvested (Prade et al., 2011).

Table 8: Moisture and yield losses according to harvest time at selected crops (average for the period 2001-2004)

Crop	Autumn harvest		Spring harvest			
	Moisture (%)	DM yield (t/ha)	Moisture (%)	DM yield (t/ha)	Moisture loss (%)	Yield loss (%)
Sorghum "Hyso"	66	9,215	42	5,756	24	37,5
Reed can. grass	50	7,214	19	5,217	31	27,3
Miscanthus	50	15,568	25	12,105	25	22,3
Knotweed "Bohemika"	62	23,059	20	14,955	42	35,1
Cannabis sativa	52	10,250	24	7,060	28	31,1
Fescue grass	48	7,252	19	5,153	29	28,9
Jerusalem artichoke	57	9,560	19	5,162	24	46,1

Source: Strašil, 2005

Prade (2011) in his doctoral thesis was focused on finding an appropriate harvest period in which the undesirable chemical fuel properties (during combustion) are at the minimum. According his research there were found following results. Combustion-related fuel properties, such as moisture, alkali, chlorine, ash content and ash melting temperature, are significantly improved when industrial hemp is harvested in spring instead of in autumn.

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[10] Physical properties, e.g. particle size, bulk density, angle of repose and bridging tendency

[11] content of major alkali and earth alkali metals, i.e. sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca), and that of silicon (Si) and chlorine (Cl), aluminium (Al), sulphur (S) and phosphorus (P).

2.4.3.4 Hemp as a source of biodiesel

Hemp biodiesel is an ester-based oxygenated fuel made of hemp oil. It comes from the pressing of the hemp seeds to extract the oil. Modification (through transesterification) makes biodiesel (FAME) able to be used directly in diesel engines. The scheme below shows the chemical reactions during the transesterification process.

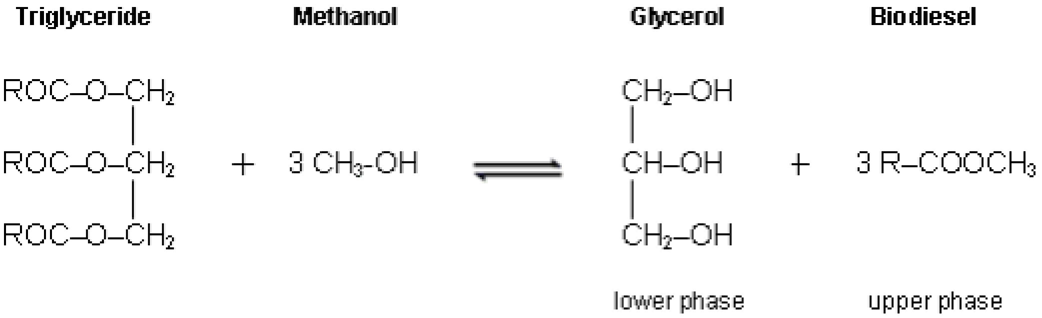

Figure 6: Scheme of transesterification process

Source: Gill et al

Available sources mainly discuss the optimization, oil characterization and the fuel property analysis of these oils and their blends. GILL et al. (2011) made a comparative analysis of hemp and Jatropha oils blends (both B10, B20)[12] used in diesel engines with the following conclusion: modifying through transesterification can improve fuel properties (slightly lower performance, higher smoke emission due to its higher viscosity). Results indicated that a B20 blend of Hemp biodiesel gives a better thermal efficiency, lower consumption and lower Co and CO2 emissions. A problem was found with higher NO_x emissions. The smoke density decreased with rising biodiesel concentration. Ahmed et al (2011) pointed out that the number of Free Fatty Acids (FFA) have a significant effect on glycerides transesterification; they make product separation and low yield biodiesel difficult to obtain. The FFA number in hemp crude oil was 1.76%, which is not exceeding 3%w so that makes hemp biodiesel the most suitable material for transesterification. Optimum conditions for FAME were found; the optimum oil to methanol ratio 1:6 at 60oC.

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[12] B10, B20 means a blend of 10 (20) % biodiesel and 90(80) % petroleum diesel fuel

2.5 Energy in ecosystems

In an ecosystem a mutual exchange of matter and energy occurs. Thermodynamic systems are characterized by an incoming and outgoing flow of energy (loss, radiation, biochemical processes, conversion of mass). The sun radiates energy 3.8 * 10 26 J / s; the surface of the atmosphere gets solar radiation with a density of 1.38kW/m2 (solar constant). The biosphere reaches 0.65kW/m2; it is 47% of solar energy striking the Earth's atmosphere. About 45% of this radiation is in the 380-750nm range. This range corresponds to the FAR (its spectral range corresponds to the absorption spectrum of photosynthetic pigments, especially chlorophyll). FAR is the only direct usable source of energy for primary production, which begins with photosynthesis.

Plants may use no more than 13% of global radiation energy; it is 27% of absorbed FAR. According to Strašil (2008), this figure is lower in real terms. Upon impact of the FAR to foliage (where there is a modification) it leads to reflection (10-20%), but the greater part of FAR is absorbed. The absorbed energy is in part bonded by photosynthesis, but most is converted into heat. FAR radiation is converted into the energy of chemical bonds. Each molecule of CO2 corresponds to the profit of potential energy of 477kJ (Strašil, 2008).

Each ecosystem is characterized by the following parts (Preininger, 1987)

- external environment and its effects
- producers
- consumers
- decomposers

Energy- material flows in ecosystems is managed by basic principles (Míša, 2000):

- The amount of energy entering the ecosystem is equal to the amount of energy escaping.
- In each transformation a part of energy leaves the system.

2.5.1 The history of energy analysis

As Špička et al.(2007) notes, the first energy analysis of the agricultural production system was the TRANSEO study in 1926 which focused on the analysis of seasonal effects of solar energy on corn growth. A more comprehensive analysis was done by Soddy (1933). His publication included not only direct energy inputs, but also indirect energy transformed into the production process. As Špička et al. (2007) mentioned, Odumen made a comparative analysis of different food systems, focusing on the conversion of fossil energy into food energy. The 1970s saw a rising interest in the energy balance in relation to the oil crisis and the response to the problem of the green revolution[13]. Pimentel et al. (1973) found that energy efficiency in this period decreased by 24%. The basis of Pimentel methodology further developed the PLANETE[14] to create the concept of energy balance at the enterprise level. A French group of scientists took into consideration the whole enterprise level, but Jelínek et al. (2008) worked out software for wheat producers.

2.5.2 Energy in agriculture

Agriculture is a sector that, on the one hand, consumes energy (fossil fuel, fertilizer, labor, etc.) and, on the other hand, transforms the kinetic energy of the sun (Strašil, 2005). Good knowledge of these bonds may lead to improved energy efficiency. Production energy in agriculture distinguishes this sector from other sectors that are only energy consumers (Picková). Špička in his research mentioned that it is necessary to address the energy balance in agriculture mainly because of the high energy intensity of agricultural production and the rising prices for energy. The agricultural sector is the largest consumer of water (70%, the majority for irrigation). Plant production as well as husbandry consumes a huge amount of fossil fuels (agricultural machinery).

2.5.3 Energy inputs

Energy inputs are represented by all the energy used and consumed in the production process. Total energy consumption in crop production is composed of a set of all sub-energy consumed in the production process and passed on to the final product with certain efficiency (Míša, 2006).

Preininger (1987) divided inputs into the following:

E0 – energy of environment, which consists of
    E01 – energy of sun radiation,

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[13] Targeted increase in energy-intensive fertilizers and pesticides, the intensification of farming, breeding more profitable varieties in third world countries.

[14] PLANETE Méthode Pour L'Analyse EnergéTique de l'Exploitation (Methodology for energy analysis of enterprises)

  - E02 – energy accumulated in soils,
  - E03 – energy of atmosphere,
  - E04 – energy of surrounded infrastructure
- E1 – direct and indirect energy inputs:
  - E11 – direct energy inputs:
    - E111 – energy of human labor
    - E112 – fossil energy (engine fuels, electricity, heating sources),
    - E113 – the other energy sources
  - E12 – indirect energy inputs (energy consumed to produce the means of production)
    - E121 –energy in machines
    - E122 – energy in products of chemical industry
    - E123 – energy in organic fertilizers
    - E124 – energy in seeds
    - E125 – the other indirect inputs (irrigation, buildings, etc.)

The French system PLANETAE (Jelínek et al., 2008) calculates the energy balance just with non-renewable energy.

The model energy balance for wheat according to Preininger (1987) with a yield of 4.7 t/ha, represented 5.3% of human labor, 16.7% of fossil energy, 14.2% energy in machinery, 50.7% of energy in chemicals and 10.1% of seed. Total embedded energy was 25.26 GJ/ha.

2.5.3.1 Direct energy inputs

According to Syrový et al.(1997) direct energy consumption in Czech agriculture varies from 45 to 50 billion GJ per year from of which 47% belongs to plant production, 37% to animal production and 16% to transport, storage and other activities.

Developing countries are based to a large extent on animal and human energy. Insufficient mechanical and electrical energy are available for agriculture, and hence the potential gains in agricultural productivity through the deployment of modern energy services are not being realized. It seems that both human and animal work will continue to be used as agricultural inputs for the future in developing countries. Efforts to support farming traditions include work on animal efficiency, which can be improved through modernization of equipment, better breeding and animal husbandry, feeding and veterinary care, and on improved designs of animal-drawn farm equipment (FAO, 2004).

Energy of human labor

Energy of human labor is considered as total consumption of hours of human labor multiplied by energy equivalent. Prenienger created his metodology in 1987. His energy equivalent for human labor was at really high level of 25,65 MJ/hour. As the author states himself, the value is higher than in the foreign literature. He justifies that by including direct energy spent in the labor process as well as energies for reproduction of living labor (maintenance).

In order to assess the energy performance of labor, the energy value of food, or the energy needed to produce food, should be considered (Bechnik, 2009). Cleveland et al. (2008) separated energy of labor into the following elements:

- the calorific value of food the worker consumes
- energy fixed in that food and
- the fuel purchased with the wages and salaries of the labor.

Energy equivalent of labor from the biological point of view is the fuel burned while human labor does mechanical work. It can be measured directly by a respirometer[15] (Cleveland et al., 2008).

In his research Bechnik (2009) observes the following: metabolic energy expenditure depends on the activity carried out (long-term activities in the 100 to 250 W range). For the recommended energy intake in the U.S. (about 14 MJ / day) total energy consumption needed for food production of 5.6 MJ / h was evaluated. The situation in the Czech Republic is only slightly different; the energy equivalent of labor determined on the basis of energy consumption for food production is about 2.3 MJ / h (Bechnik, 2009). The author also supposes that it would be better to consider only the difference between energy expenditure at rest and energy expenditure at work. The difference is usually up to 100 W.

It is also possible to consider the equivalent of labor force as a share of dietary energy supply. Human beings need energy for the following: basal metabolism (45-70%), metabolic response to food (10%), physical activity (20-45%). According to BMR factor the daily energy requirements for men 30-60 years old, weighing around 80 kg, leading an active lifestyle is determined by FAO at the level of 16.5 MJ per day (FAO, 2004).

Petr et al. (1997) used in their calculation the energy equivalent of 0.628 MJ/ha. The French project PLANETE (Jelínek, 2008) does not use the energy of human labor in their

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[15] Respirometer measures the rate at which oxygen is combined with food to produce CO_2 + work

balance at all. They do not consider renewable energy in their balance; they take into account just non-renewable.

Fossil energy

Intensity of energy in crop production depends on the level of technology and suitable organization of work. Fuel and energy consumption can be evaluated in relation to the unit area or unit of production.

The most demanding on fuel consumption is tillage in which 45 liters of diesel per hectare is consumed. In Czechoslovakia in 1980, agriculture accounted for 5.6% of total fuel consumption. Energy intensity can be decreased by appropriate selection of mechanization or omitting of operations (Syrový et al., 1997). Around 10% of fuel consumption can be saved through a minimum soil cultivation. There are many scientific publications that deal with reduction of energy consumption and potential savings in fuel consumption. Krejčíř et al. (1987) mentioned supplementary power vested in crop rotation in traditional soil cultivation averages 20 GJ per hectare each year.

The energy equivalent for diesel also varies: 47.77 MJ/l [Červinka, 1980, cit. by Míša, 2000], 35.28 MJ/l (Preininger, 1987), 35.8 MJ/l PLANETE. Last mentioned content of energy in 1.17 l of diesel, when 0.17 liters is considered energy for extraction, refining and transport one liter of diesel.

2.5.3.2 Indirect energy

Energy in machines

A part of the calculation of indirect energy inputs is the energy embodied in machinery and equipment, or energy embodied during manufacturing. How Preininger expected the corresponding share of energy is continually insert into production process during lifetime of machinery (equipment). Preininger (1987) considered the specific consumption of energy for production machines, related to the unit weight of the machine an average of 100 MJ/kg and the complexity of machinery differentiates it: truck (146 MJ/kg), tractor (134 MJ/kg), self-propelled machine (119 MJ/kg), stationary unit (92 MJ/kg), outboard engine complex (88 MJ/kg) and simple outboard engine (63 MJ/kg).

Hill et al. (2006) in his research on the “Energetic costs and benefits of biodiesel and ethanol biofuels”, they assumed its embodied energy that consist entirely of steel. It takes 25 MJ/kg to produce steel and an additional 50% energy use for assembly.

PLANETE (Jelínek, 2008) created a new methodology for enterprises energy calculation, where were used equivalent as Table 9 shows.

Table 9: Energy equivalents for indirect energy inputs embodied in machines and equipments

Tractors	95.7 MJ/kg
Tillage machines and equipments	99.2 MJ/kg
Sowing machines and equipments	95.4 MJ/kg
Spreaders	95.4 MJ/kg
Harvesters, mowing machinery	83.5 MJ/kg

Source: Jelínek et al. (2008)

Energy in products of chemical industry

Picková et al. (2007) mentioned that in crop production there are important energy inputs in the form of fertilizers (mainly nitrogenous) and plant protection agents; nevertheless Hulsbergen et al argue that the consumption of mineral nitrogen decreases but plant protection agents increase. How Strašil et al. (2005) states to produce one ton of nitrogen requires energy 87.5GJ, for comparing phosphate fertilizers need 17.75 GJ and potassium 9.6 GJ. According to report of MŽP (ME, 2009) using fertilizers in the Czech Republic has been changing since 1990, when agriculture was transformed; there was a very substantial decrease in the consumption of mineral fertilizers and lime materials. The application of these materials increased again in 1994 and has changed a bit since then. At the present time, the application of fertilizers in the Czech Republic corresponds to the EU average.

Preininger (1987) recommended in his methodology energy equivalents for the conversion 1 ton of pure nutrients: N - 82.5 GJ, P_2O_5 - 17.7 GJ, K_2O - 9.6 GJ, while Jelínek (2008): N -82.5 GJ, P_2O_5-5.39 GJ, K_2O-12.1 GJ and CaO 2.8 GJ.

Energy in organic fertilizers

Preininger (1987) determined the energy content of organic fertilizer to be 463 MJ/t for manure, 246 MJ/t for cattle slurry and 200 MJ/t for compost, based on VÚRV methodology in Prague - Ruzyne by comparing the average content of pure nutrients with the corresponding energy equivalents of fertilizers. Krejcir et al. (1987) the dry matter content multiplied by heat combustion of cellulose. Míša (2000) took into consideration 2.46 GJ/t, when taking into account the average content of organic matter in manure 14% (maturing from 3 to 5 months)and heat of combustion of cellulose 17.58 GJ/t.

Energy in seeds

Preininger (1987) mentions some energy values for seeds, energy for production including. For example wheat with a considered norm sowing rate 220 kg/ha – 2.59 GJ/ha, rape 10 kg/ha - 0.35 GJ/ha, flax 120 kg/ha -4.86 GJ/ha. But in his formula was mentioned more indicators as purchase price of seed, average purchase price of crop, energy content of production and standard sowing rate.

2.5.4 Energy outputs

Energy outputs are formed - by produced biomass and by irreversible energy losses. Preininger (1987) designated produced biomass as the sum of main and by-products, residues and root biomass. Irreversible loss of energy - the energy accumulated in the soil (from the non-harvested biomass) increase, according to author, entropy of the environment. The amount of biomass produced depends on the biological properties of cultivated crops, optimum conditions of directed technological processes (purposeful energy deposits).

The best method is to determine gross energy (calorific value) of dry matter unit.

The value of the gross energy is relatively stable 17.58 GJ /tone of dry matter (calorific value of cellulose (Preininger, 1987).

Preininger (1987) divides energy outputs as follows:

- E2 - Energy of utility plant production:
  - E21 - energy content of the main product,
  - E22 - energy content of by-product
- E3 - energy crop residues (including root biomass),
- E4 - irreversible energy losses.

2.5.5 Energy balance

Balance is an objective measure of efficiency; quantification of inputs and outputs enable energy rationalization measures and evaluation of technologies for energy inputs (Preininger, 1987). The historical shift in the balance occurred when kinetic energy (power provided by animals and humans) was replaced by engines running off of fossil fuels (Picková et al., 2007). Energy balance was in equilibrium (energy was consumed as much as it was produced from the sun, water, wind and work of animals and humans) until non-renewable energy sources were discovered (Špička et al., 2007).

Energy balance serves for the assessment of production processes. Energy balance, according to Preininger (1987), reveals the existing reserves and optimizes inputs to the production processes with respect to production of the maximum effect at low specific energy consumption. Gomiero et al. (2008) compared conventional and organic farming. Organic has a better energy efficiency (ratio of inputs to outputs) while conventional agriculture is less efficient but has a higher net energy production per unit area.

3. OBJECTIVES

Overall objective: Energy evaluation determining for processes leading to industrial hemp utilization for energy. Choose which of these technologies is the most suitable from energy point of view.

Specific objectives are following:

1. Determining energy balance of hemp used for solid biofuels in autumn harvest.
2. Energy balance calculation of hemp stalks grown for solid biofuels in spring harvest.
3. Assessment of EROEI for both way of utilization.

4. MATERIAL AND METHODS

4.1 Material

The hemp plant (Cannabis sativa L.), variety of Polish origin – Bialobrzeskie belongs to a medium-early maturity group, which is grown mainly for fiber utilization. Industrial hemp was grown in 2009 and 2011 to evaluate spring and autumn harvest. Row spacing was 12.5cm, seed rate 40kg/ha and sowing depth 3 cm. Autumn part was sown on a trial plot of size 0.01 ha, spring part 0.0005 ha in the district of Prague – Suchdol. The fields were located according to coordinates 50°7'52.372"N, 14°22'11.299"E with altitude of 285 m over the see. Neither fertilizers nor pesticides were used in both experiments. Growing season lasting 184 days (May-October) had a sum of precipitation[16] during growind period 358.7 mm and sum of temperature[17] 2,904.1 °C. Spring harvest, provided in March 2012 (growing season 285 days) refers sum of precipitation of 389 mm and sum of temperature 2,367.8 °C during growing period.

4.2 Sample analyses

Yield of hemp was determined by collecting all plants and weighting. Fields and harvesting loses are not including in calculation.

Plants for sampling were hand-cat close to ground, for laboratory analysis was chosen stems of different part of trial plot and from different parts of plants containig chaff, fibres, leaves and seeds with random. Samples for MC analysis were dried for 24 hours in the automatic hot air dryer. The water content of biomass after drying was less than 1%. At the balance of precision (with an accuracy of 0,001g) the samples of experimental hemp plants were weighed. MC was determined from the difference before and after drying.

Laboratory determination of the gross calorific values was carried out in adiabatic calorimeter type MS 10A (producer: LAGET, Ltd.). All measurements were repeated for 15 times. To the statistical processing of results was used calculator CASIO fx115 MS.

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[16] Precipitation accumulated from sowing date till harvest

[17] Accumulated temperature (average day temperature above 0°C) from sowing date till hervest

4.3 Biomass energy yield calculation

According to MC of plants, which was measured in laboratory, dry matter of yield was determined by formula. BEY (maximum potential biomass yield) was in the thesis calculated by multiplying the dry matter (DM) yield by GCV (gross calorific value).

4.4 The frame of technological energy efficiency determination

The system was identified with the land (field), while the input was considered everything that comes from outside the site, the outputs of what goes from the field (it is taken away). We do not take into consideration energy of solar radiation and energy of crop residues remaining in the soil.

4.5 Technological process of cultivation Cannabis sativa

Technological energy efficiency was determined for large-scale utilization, for that reason procedures are defined according to the Research Institute of Agricultural Engineering (technological procedures for crop rotation). They contain recommended chronological sequences of manufacturing operations (fertilization, soil preparation, sowing, care during vegetation, harvesting, transport, field treatment after harvest) as well as repeatability operations and material inputs (material name, unit of measure, quantity per hectare). All procedures are based on average conditions and intensity of production. Technological processes taken into consideration are shown in the annex.

Briquetting lines of Brikstar company were took into consideration for phytomass post-harvesting treatment of solid biofuels. Briquetting lines were designed for the autumn harvest and for spring harvest separately. Line BRISUR 800, which content dryer (desiccators) is suitable for autumn. For spring harvest it was considered briquetting line Brikstar 200. Both designed lines are completed by crusher and separator HIMMEL of power 22kW.

4.6 Energy balance

Energy balance was determined according to the methodology of FMZVž No. 7/1987 titled "Energy evaluation of processes in crop production" (Preininger, 1987).
Conversion of energy equivalents were taken from listed sources (table 10).

Table 10: Energy conversion equivalents

Item	Unit	Energy equivalent	Source
Human labor	1 h	2.3 MJ/h	Bechnik (2009)
Diesel	1EQF*	35.8 MJ	Jelínek et al. (2008)
Electricity	1kWh	3.6 MJ/kWh	Preininger (1987)
Methane	1m3	35.8 MJ/m3	VUZT
Steel	1 kg	25 MJ/kg	Hill et al. (2006)
Fertilizers			
P (P_2O_5)	1t pure nutrients	5,394 MJ/t	Jelínek et al. (2008)
K (K_2O)	1t pure nutrients	12,100.4 MJ/t	Jelínek et al. (2008)
Ca (CaO)	1t pure nutrients	2,799.56 MJ/t	Jelínek et al. (2008)
N (100%)	1t	82,500 MJ/t	Jelínek et al. (2008)
Superphosphate (19% P_2O_5)	1t	1,024.86 MJ/t	Own conversion
Limestone (87,5% CaO)	1t	2,449.62 MJ/t	Own conversion
Ammonium sulphate (21% N)	1t	17,325 MJ/t	Own conversion
Pottasium salt (60% K_2O)	1t	7,260 MJ/t	Own conversion
Farmyard manure	1t	463 MJ/t	Preininger (1987)

4.7 Energy inputs

Direct inputs; the amount of fossil fuels and human labor were taken from the norms for agricultural production (Kavka et al., 2008), which were multiplied by their energy equivalents (table 10).

Indirect inputs

Production energy in machines and energy in fertilizers was calculated according to formula of Preininger (1987). Weight of tractors, machines and tools were searched in the catalog of agricultural machinery (VÚZT). It was found type machine for each operation that matches given parameters. Energy equivalents for indirect energy inputs embodied in machines and equipments (conversion coefficient) were calculated according to Jelínek (2008). Recommended hours for the machines´ uses during year were taken from the norms (Kavka et al., 2008), lifetime was calculated 15 years (world average). Coefficients of increasing indirect energy inputs in machines by repairing and maintenance during its lifetime were taken from Havrland (table included in annex). Time of working operation performing (group of operations) calculated according to norms (Kavka et al., 2008).

For industrial hemp grown for biomass, it is consider 60kg of nitrogen, 60kg of phosphorus, 60 kg of pottasium of pure nutrients which is equal 0.25t superphosphate, 0.1t potassium salt, 4.5t farmyard manure and 0.3t ammonium sulphate.

Industrial hemp seed sowing rate (60kg/ha) as well as value for gross calorific value (22.85MJ/kg) was taken from VÚZT. It is not taken into consideration energy for seed production and other processes connected with seed storage.

Indirect energy in briquetting lines were calculated according to Hill et al. (2006) on the basis of energy needed for steel production increased by 50% (chapter indirect energy - review). Weight lines estimated on the basis of individual components. Lifetime considered 15 years, annual use 350 days, 16 hours a day.

4.8 Energy profits

Energy profits were calculated as differ between energy outputs (BEY per hectare) and energy inputs.

4.9 Energy return on energy invested EROEI

EROEI = gross energy yield / energy expended, or energy efficiency, which is used as different methods of energy evaluation. The output/input energy ratio is proposed as the most comprehensive single factor in pursuing the objective of sustainability.

5.1 Energy outputs determined by calorimetric method

Autumn harvest

A growing season of lasting 184 days produced 24.3t/ha of green and 10.93t/ha of dry biomass. Gross calorific value was 17,043 MJ/kg with standard deviation 0,213 MJ/kg, which determined that the energy yield of dry matter was 186,28 GJ/ha.

Table 11: Moisture content, biomass yield, dry matter yield, GCV, energy output for autumn harvest

	Moisture at harvest (%)	Biomass yield (t/ha)	Dry matter yield (t/ha)	GCV (GJ/t)	Energy yield(GJ/ha)
Bialobrzeskie (2009)	55.02	24.3	10.93	17.04	186.28

Spring harvest

Spring harvest in March 2012 produced a 31% decreased biomass yield with a moisture content of 19.09 and its GCV at a level of 19.31 MJ/kg with standard deviation 1.023 MJ/kg. The determined gross energy yield for this kind of harvest 145.59 GJ/ha.

Table 12: Moisture content, biomass yield, dry matter yield, GCV, energy output for spring harvest

	Moisture at harvest (%)	Biomass yield (t/ha)	Dry matter yield (t/ha)	GCV (GJ/t)	Energy yield (GJ/ha)
Bialobrzeskie (2012)	19.09	10.33	7.54	19.31	145.59

5.2 Energy inputs

Energy inputs for commodity balance of hemp (Cannabis sativa) grown for energy purposes shown in table 13 in full detail. Share of input sums as well as proportion of direct and indirect inputs for autumn and spring harvests are described.

Table 11: Energy inputs for commodity balance of hemp

Operation	Human labor MJ/ha	Fuels MJ/ha	Machines MJ/ha	Fertilizers seed MJ/ha	Sum MJ/ha
Liming	0.048	16.826	2.43	489.4	508.704
Fertilizing 1	0.322	82.340	48.59	982.215	1,113.467
Fertilizing 2	0.286	107.400	3.43	2,083.5	2,194.616
Fertilizing 3	0.253	64.440	34.00	5,197.5	5,296.193
Fertilizing sum	0.909	271.006	88.45	8,752.615	9,112.98
Deep tillage	1.91	930.8	265.88		1,198.590
Hauling	0.506	179	17.73		197.236
Seedbed preparation	0.552	293.56	64.50		358.612
Stubble- tillage	0.575	200.48	32.35		233.405
Tillage processing sum	3.543	1,603.84	380.46		1,987.843
Sowing +seeds	0.667	125.3	59.37	1,371	1,556.337
Transport	3.381	225.54	96.12		325.041
Mowing	1.633	269.5	80.85		351.983
Compressing	1.541	173.25	76.5		251.291
Briquetting line 1	107.209	8,288.280	173.414		8,568.903
Briquetting line 2	91.790	2,994.134	178.153		3,264.077
Sum autumn	118.883	10,956.716	955.164	10,123.62	22,154.378
Sum spring	103.464	5,662.570	959.903	10,123.62	16,849.552

Fertilizing 1 – superphosphate (0.25t), potassium salt (0.1t)

Fertilizing 2 – farmyard manure (4.5t)

Fertilizing 3 – ammonium sulphate (0.3t)

Briquetting line 1 – for autumn harvest, separator, crusher and desiccators included

Briquetting line 2 – for spring harvest, separator and crusher included

Autumn harvest energy inputs

Autumn harvest with its inputs 22,154 GJ/ha creates 11.8% of outputs.

Figure 7 shows values for particular parts of consumed energy during hemp growing taken from autumn harvest. In descending order – fossil energy (10,957MJ/ha), energy in fertilizers (8753 MJ/ha), energy in seeds (1,371 MJ/ha), energy in machines (955 MJ/ha) and energy of human labor (119 MJ/ha) which represent: 49.46%, 39.51%, 6.19%, 4.3%, and 0.54%, respectively.

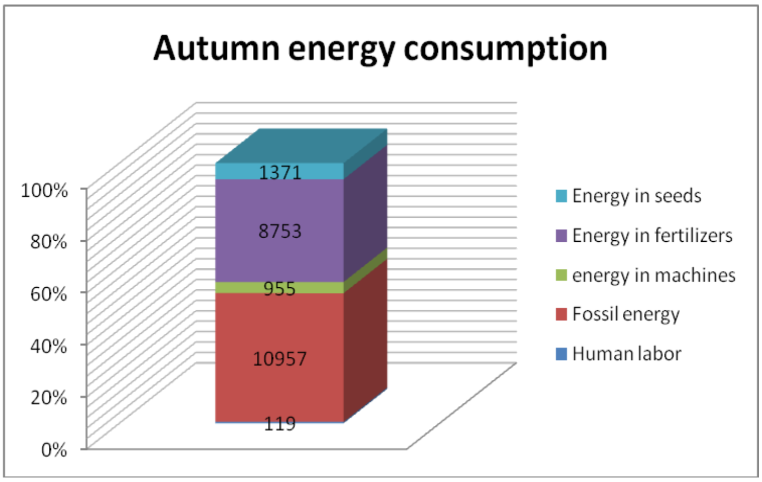

Figure 8: Autumn energy consumption

Share of direct and indirect energy inputs on total inputs represented figure 8. It can be easily seen that share is almost equal: 49.99%(direct) to 50.01%(indirect).

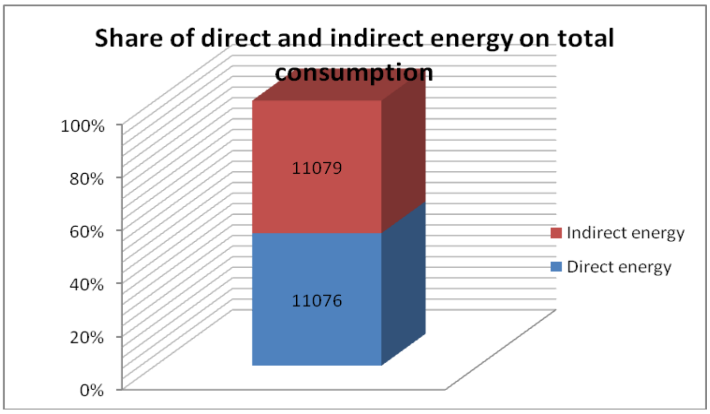

Figure 9: Share of direct and indirect energy inputs on total energy consumption (autumn)

Fossil energy

The graph 9 represents share of FF used mainly during field operations and for transport and electricity, which is used in after harvest processes.

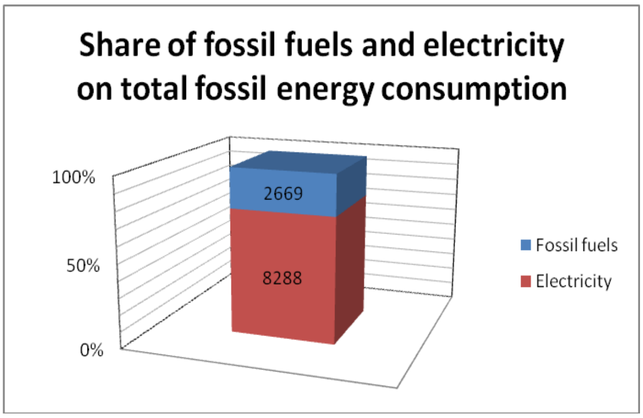

Figure 10: Share of fossil fuels and electricity on total fossil energy consumption (autumn)

For autumn harvest the main share is created by electricity (8,288 MJ/ha), that represents 75.64 %, which is used in briquetting line, including high power separator, crusher and desiccator.

Fertilizers

Next largest component of energy inputs is products of the chemical industry plus organic fertilizers (farmyard manure).

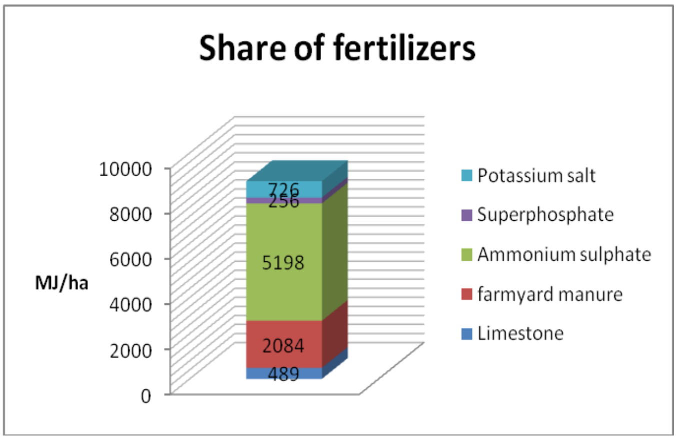

Figure 11: Share of fertilizer (autumn, spring)

In the graph above (figure 10), it can be seen that used chemicals bear energy (8,753MJ/ha) in following order: Ammonium sulphate (59.4%), farmyard manure (23.8%), potassium salt (8.3%), limestone used for liming (5.6%) and superphosphate (2.9%). The amount and proportion of limestone and fertilizers used are the same for spring harvest.

Spring harvest energy inputs

Spring harvest with energy inputs 16,849 GJ/ha creates 11.5% of energy outputs. Figure 11 shows consumed energy during hemp growing with spring harvest. In descending order – energy in fertilizers (8,753 MJ/ha), fossil energy (5,663 MJ/ha), energy in seeds (1,371 MJ/ha), energy in machines (960 MJ/ha) and energy of human labor (104 MJ/ha) which represent: 51.95%, 33.61%, 8.14%, 5.7%, and 0.62%, respectively.

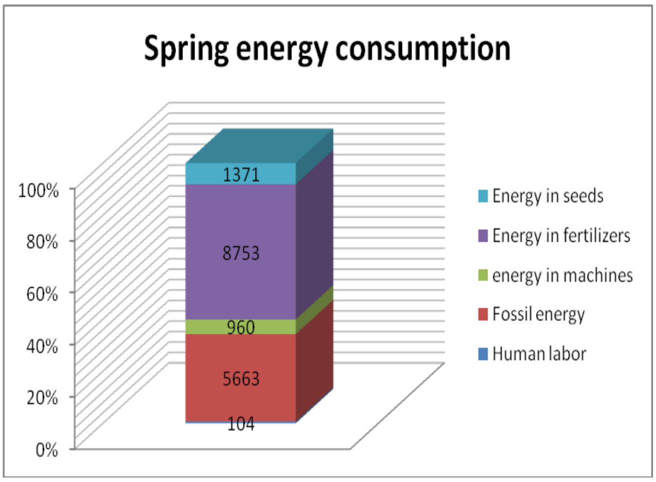

Figure 12: Spring energy consumption

Share of direct and indirect energy inputs on total inputs (16,850MJ/ha) is represented in graph 12. It is easily seen that unlike in the autumn harvest, when the proportion of total imputs was equal, during spring harvest, consumption of indirect energy is noticeably higher (65.8%).

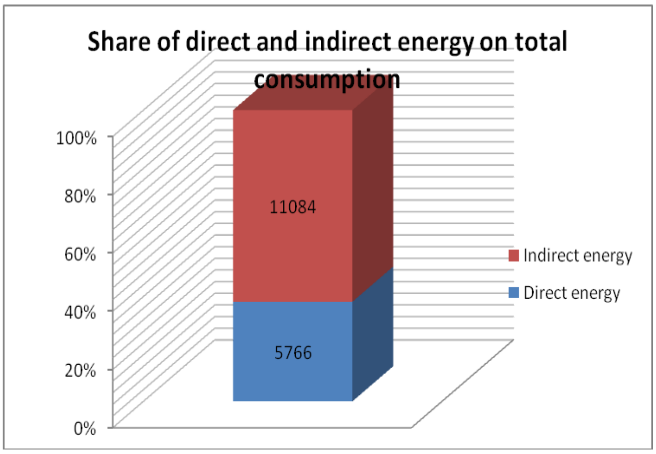

Figure 13: Share of direct and indirect energy on total energy consumption (spring)

Fossil energy

Spring harvest consumes 2,994 MJ per hectare of electricity and 2,669 MJ/ha of energy in fossil fuels, mainly diesel for engines with percentage shares of 52.87% and 47.13%, respectively. There is a significant reduction in electricity due to the elimination of desiccator, which is not necessary because the moisture content is lower (19%).

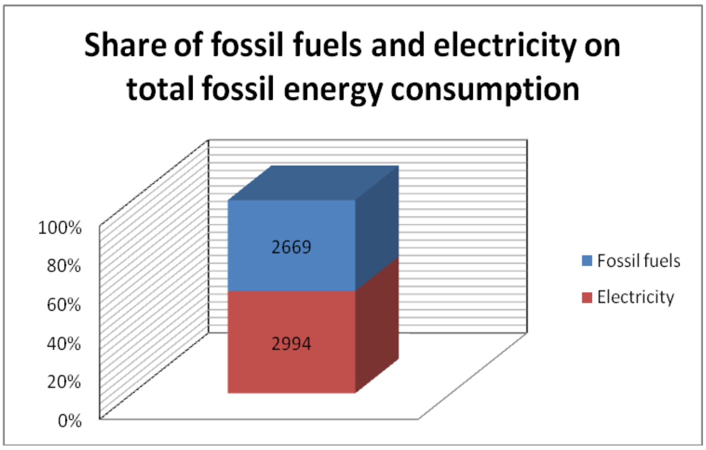

Figure 13: Share of fossil fuels and electricity on total energy consumption (spring)

5.3 Energy gain, energy return on energy invested

The difference between energy output and energy inputs was calculated at:

164.13GJ/ha for autumn harvest and
128.74GJ/ha for spring harvest.

EROEI (energy efficiency), which is a quotient of outputs to inputs. It was determined to be: 8.41 for autumn and
8.64 for spring harvest.

5.4 Evaluation of results and their discussion

5.4.1 Energy outputs determined by calorimetric methods

Biomass yield of industrial hemp is the most important factor affecting better efficiency. Yield can be influence by several factors: weather conditions (precipitation , temperature), sowing rate, period of sowing, time of harvest, fertile soil (Prade, 2011; Strašil, 2005).

After several years of experimental cultivation, Swedish researchers have recognized that biomass yield depends on climatic conditions, mainly accumulated temperature and precipitation. Furthermore, Sladký recommended the most appropriate sum of precipitation should be more than 500 mm. Cannabis in the above mentioned period was grown under a temperature sum of 2,904.1 °C (autumn), and 2,186 °C (spring), which can be considered above average. Although the temperature was suitable, precipitation (358.7 mm autumn and 389.1 mm spring) and their lack during germination was not ideal for cannabis in terms of growth and biomass yield creation. Not one of the experiments fulfilled this requirement.

For flowering cannabis needs a day shorter than 14 hours. Therefore the ideal period of cannabis sowing is estimated to be from May 1st to 10th. A significant difference in biomass yield seems to be in the choice of the high yielding variety. According to trial experiments which have not been published yet, it is possible to find hemp varieties able to create 38% higher BM yields (Ferimon).

It should be noted, however, that when conditions are unfavorable, industrial hemp (Cannabis sativa) is one of a few plants on earth that is able to create at least 11 tons of dry matter within a period of 150 days. Graph 15 below shows the growing characteristics of the Bialobrzeskie hemp variety grown in 2009 in Suchdol. It can be seen that Cannabis sativa reaches the highest growth in the period between 27th- 62nd day after sowing. Full details describes Bachelor thesis „Testing selected energy crop – industrial hemp“.

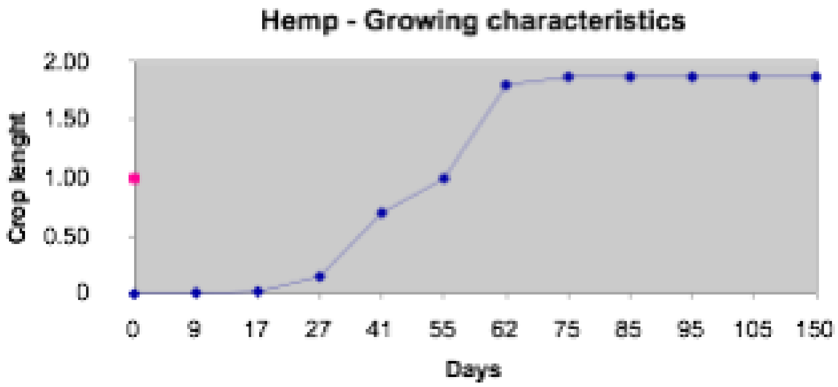

Figure 14: Growing characteristics of hemp during season May-October 2009

In this thesis of hemp energy balance two kinds of harvests are compared: spring and autumn. In autumn, the moisture content in plants is relatively high (55%) but BY is also high (10.93 t of dry matter). In spring harvest, yield falls by 31%, but the decreased water content (19%) means that there is no need for using dryers for post harvest treatment. Moisture content in stems during spring harvest (19%) was lower than Strašil recognized. MC in hemp plant on his trial plot after winter was 24%. Parade's experiments with moisture contain between 12-22% in biomass in plant parts 20cm above ground.
Therefore, depending on the intended use of biomass in individual cases, look for a compromise between the date of harvest, moisture content and loss of phytomass.

Scientific institutions dealing with this issue agree that the spring harvest is better in terms of efficiency and less overall fuel combustion –related fuel properties (Prade, 2011), such as moisture, alkali, chlorine, ash content and ash melting temperature all significantly improve when industrial hemp is harvested in spring instead of in autumn.

It is also necessary to mention that industrial hemp has advantages over other energy crops - low pesticide requirements and good weed competition. Hemp crop, when the sowing rate is high (60 kg / ha), is able to suppress weeds. In areas with lower sowing rates weeds appear at an early stage; however, for cannabis plants weeds were not the competitor.

Gross calorific value (GCV) in autumn was lower (17.04MJ/kg) than in spring (19.31 MJ/kg). All results correspond with the Swedish results (Kreuger et al., 2011) with a significant increase from 17.5 MJ/ kg in July to an average of 18.4 MJ/ kg during the period August-December and a further increase to an average of 19.1 MJ /kg during January-April.

The hemp plant (Cannabis sativa L.) a variety of Bialobrzeskie in the experiment in the Suchdol district of Prague in years 2009 and 2011 ensured DM yield 10.93 t/ha, GCV 17.04 GJ/t with gross energy outputs 186.28 GJ per hectare (autumn) and DM 7.54 t/ha , GCV 19.31 GJ/t with gross energy output 145.59 GJ per hectare (spring). There are just small differences among results of other researches. Compared trials: Hutla (2004) for autumn harvest considers dry matter yield 10 t/ha and GCV 18.064 GJ/t with gross energy output 180.64 GJ/ha. Strašil (2005) mentions DM yield 10.25 for autumn harvest and 7.06 t/ha for spring harvest. The author unfortunately does not state the value of GCV, so his results of field trials were recalculated according to GCV of our laboratory. Autumn: 174.66GJ/ha, spring: 136.33GJ/ha.

5.4.2 Energy inputs

Energy inputs were multiplied by coefficients, which were considered the most appropriate. Some of inputs (seeds), however, were counted as their energy value only, not surplus energy required for their processing. Table10 includes the used the conversion coefficients.

Indirect inputs in technological operation

In table 1 (in annex) shown results of indirect energy inputs for each individual technological operation, which are 955 MJ/ha for autumn and 960 MJ/ha for spring harvest. As is evident from the survey, the largest indirect energy consumer is deep tillage with 266MJ/ha following with indirect energy in briquetting lines (178 MJ/ha spring, 173 MJ/ha autumn). Some operations do not happen each year (liming, manure fertilizing), so only their ratio for each year is taken into account. According to the Research Institute (VÚZT) the repetitiveness of the operation given is based on average conditions and intensity of production. But they may vary in dependency on soil conditions.

In his dissertation Míša (2000) also calculated individual processes. Most of our calculations on average coincide with Míša's calculations. Preininger (1987) in his methodology calculated energy in technological processes for several crops. Neither energy crops nor hemp were included in 90s. Example is given for flax (MJ are related to operation): soil preparation 520 MJ, fertilizing 110 MJ, sowing 90 MJ, harvest 1.570 MJ, post -harvest treatment 540 MJ, sum 2.830 MJ. Preininger results are 3 times higher (comparing with our 960 MJ/ha) which is caused by using the different energy equivalents embodied in machines.

There are taken into consideration briquetting lines of Brikstar Company for phytomass post-harvest treatment for solid biofuels. They were discussed by Mr. Libor Kejř, Msc. Briquetting lines were designed for the autumn harvest and separately for the spring harvest. Due to the large amount of water in plants while harvesting in autumn, it is necessary to use line BRISUR 800, which contains dryer (desiccators). The line is supplemented with crusher and separator HIMMEL of power 22kW. For spring harvest briquetting line Brikstar 200 were considered, supplemented with separator and crusher like the previous one. According to a representative of the above mentioned company, it is more than probable that fibers, which are part of hemp stalks, would cause a problem while crushing. Thus, the company recommends the spring harvest when the tenacity of the fibers are weaker. All technical details are available on Brikstar's webpage.

Pelleting of hemp stalks can be also taken into account. Due to possibility of higher moisture content of pelleting material is probably more appropriate. Energy intensity would vary only slightly because crusher and separator must also be added to the pelleting line.

Preininger mentioned that energy balance should reveal hidden reserves. A solution for technological operation should be the unification of operations, using modern technologies and new machines, which are characterized by low fuel consumption.

Indirect inputs in fertilizers

For industrial hemp grown for biomass, 60kg of nitrogen, 60kg of phosphorus and 60 kg of potassium result in 8,753.14 MJ/ha. As compared with Hutla (2004) – 10,933 MJ/ha.

It would be also possible to decrease the amount of fertilizers. As Prade (2011) wrote, nitrogen, which is a major consumer of energy inputs, is not a limiting factor for hemp cultivation. If the amount of ammonium sulphate is decreased by 50%, total energy inputs would decrease by 2,598.75 MJ/ha, which is 11.7% for autumn harvest and 15.4% for spring harvest.

Direct inputs

Fossil energy

The leader consumer for autumn harvest (10,957 MJ/ha), the main share is created by electricity (8,288 MJ/ha) which is used in briquetting line, including high power separator, crusher and desiccator. For all phytomass with moisture content over 20%, additional energy inputs must be considered in the form of drying, which are characterized by high energy demands. In the case of hemp, the majority of electricity consumption occurs in the desiccator (3,188 MJ/ha, that is 38.47% of electricity consumption, 29.1% of total fossil energy and 14.39% of total energy inputs). During spring, there is a significant reduction in electricity due to the elimination of desiccators, which are not necessary because the moisture content is lower (19%).

Spring as well as autumn harvest consumes 2,669 MJ/ha of energy in fossil fuels, mainly diesel for engines. The theoretical calculation of diesel consumption necessary for technological processes can vary from the actual amount needed. The norms were formed according to the average consumption of machinery. The question remains whether farm machinery and equipment are not outdated; which is characterized by increased consumption of fuel and lubricants, and a higher demand for maintenance costs. Outdated technology, which, due to slow restructuring of the agricultural field, affects the amount of energy inputs to production processes. In the next few years, outdated technology can be replaced by competitive foreign technologies.

Human labor

Proportionally the smallest part of energy inputs. Human labor demand for the whole process of hemp utilization for briquettes is 45 hours for autumn harvest and 51.7 hours for spring harvest. The difference is caused by different human labor demands for processing solid biofuels.

The amount of human labor energy depends on an appropriate energy equivalent. According to Bechnik (2009) this experiment takes into consideration 2.3MJ/hour, which is determined on the basis of energy consumption for food production in the Czech Republic. Míša (2000) used 25.65 MJ/hour for his energy balance value. According to Prenienger (1987), this figure is too high. As the author states himself, the value is higher than in the foreign literature. He justifies that by including direct energy spent in the labor process as well as energies for reproduction of living labor (maintenance).

5.4.3 Energy balance

The difference between energy output and energy inputs 163.13 GJ/ha with EROEI 8.41(autumn hemp harvest) compared with spring hemp harvest results 128.74 GJ/ha with EROEI 8.64 are similar to Hutla (2004) results. Hutla created hemp balance for autumn harvest with the following results: EROEI 8.78 (where energy outputs were 180.64 GJ/ha, inputs 20.581 GJ/ha). The figure is comparable with our experiment.

Compared results and recommendations from other scientific institutions, which deal with this issue, they prefer as well as this thesis spring harvest of Cannabis sativa. The reason is not only in terms of efficiency, but they recommend it from the point of better fuel combustion –related fuel properties (Prade, 2011), such as moisture, alkali, chlorine, ash content and ash melting temperature, which are significantly improved when industrial hemp is harvested in spring instead of in autumn.

Energy balance is determined on the basis of the methodology Preininger (1987) gave us in an outline to find more modern approaches and methods. The energy balance of cannabis sativa was calculated for given conditions. The commodity balance, however, has some drawbacks.

Energy balance for the assessment of agricultural systems or commodities does not include the highest input – solar radiation. Although this represents about 98% of energy (Preininger, 1987), it is very difficult to make a precise measurement of solar radiation as well as measure the amount of energy entering the leaf and affecting photosynthesis. The second most important energy in the system which is also really difficult to calculate is the energy of crop residues remaining in the soil.

Another very important weakness of the commodity balance is its accuracy, which depends on the appropriate choice of energy conversion equivalents. They are not uniformly established and authors dealing with this issue found (in both domestic and foreign literature) a number of very different values, such as the equivalent of the human labor range from 628 kJ (PETR, et al., 1997) to 25.65 MJ (Preininger, 1987).

As Míša (2006) notes in his doctoral thesis, most of “additional energy” is not a direct source of energy used to produce crop yields, but serves as a means to regulate energy processes. This is not the case of cannabis, which achieves the desired yield regardless of using pesticides, herbicides and other plant protect chemicals. In terms of resistance, weed control and biomass production in a short time, cannabis is really unique.

Each commodity balance consists of two basic elements – inputs and outputs. If a positive effect on this balance is lacking, outputs (yield, GCV) must be increased and/or inputs (fertilizers, unification of technological operations, etc.) reduced.

Energy commodity balance of industrial hemp was formed for given conditions in this thesis. Although we tried to take into account all theoretical aspects that could occur under field conditions, the real situation may be quite different.

However energy efficiency seems to be objective measurement for commodity and enterprise evaluation of energy resources, comprehensive evaluation like effect on ecosystems, environmental impacts, social effect and other does not include.

Suggestion for further research

Due to outdated methodology, a new methodology should be developed. It should contain all energy conversion equivalents to eliminate differences in individual research.

The most modern scientific evaluation of how a given product influences the environment seems to be LCA (Life Cycle Assessment) which is defined in international standards and is widely used by experts for analysis products to the declaration of their impact on the environment or to compare different alternatives. It consists of four phases based on ISO standards. Outputs of LCA are wastes, emissions, noise, vibrations, and radiation. Life cycle assessment is still a young discipline, and it is continually developing.

A Life Cycle Assessment- the overall impact of biofuels made from hemp to the environment- should be also created.

6. CONCLUSION

The given results and subsequent analysis point to the following conclusions:

- Hemp (Cannabis sativa), which is characterized as a high – yielding and high GCV value energy crop, is suitable for production of solid biofuels in the climatic conditions of the Czech Republic.
- Hemp has a good energy output to-input ratio and is therefore an above-average energy crop. Regarding which is more efficient, autumn or spring harvest, it was found that for conditions listed in the thesis, the spring harvest should be preferred because its energy efficiency is higher as compared with the autumn harvest.
- Advantages over other energy crops are also found outside the energy balance, e.g. low pesticide requirements, good weed competition.
- Targeted scientific research in yield improvement may determine this crop as among the best energy crops for our climate.

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ANNEX

List of annex

Annex 1 Indirect energy inputs for individual technological operation

Annex 2 Values of repair constant and repair exponent used in the calculation of accumulated repair costs for various types of machines

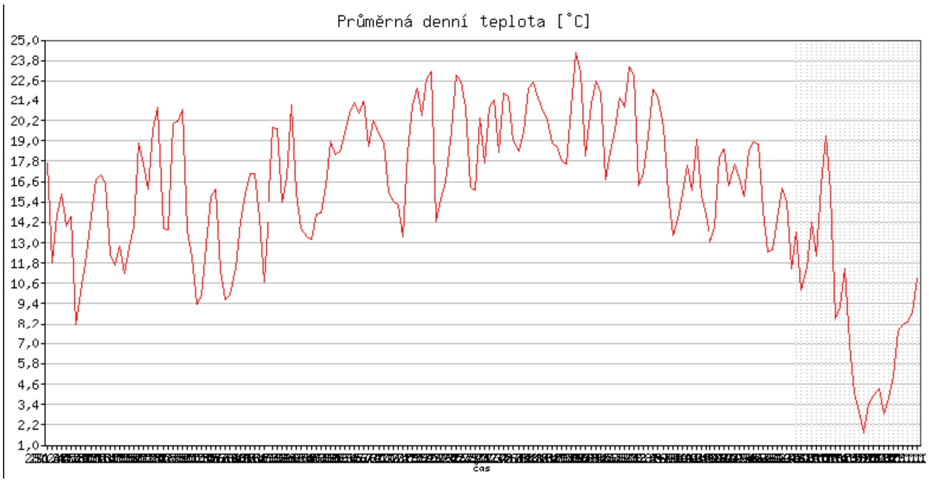
Annex 3 Average daily temperature for growing season (May – October) 2009

Average daily temperature for growing season (June– March) 2012

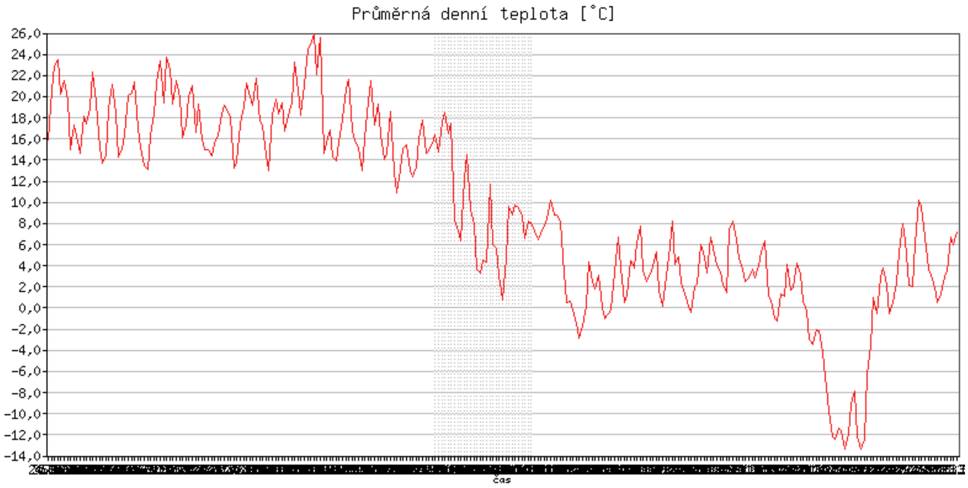
Table 1: Indirect energy inputs for individual technological operation

Working operation	Technical performance	Indirect energy embodied in machines (MJ/hour)	Time spent on operation (hour/ha)	Indirect energy in operation (MJ/ha)
Liming up ot 2t/ha	Self-propelled fertilizer spreaders	97.17	0.25 *0.1 r	2.43
Fertilizing 0.31-0.6 t trans. Included	Self-propelled fertilizer spreaders	97.17	0.5	48.59
Manure spreading; loading +trans. Included	Fertilizer spreaders	101.05	0.05 h/t (4.5t* 0.15r) =0.034	3.43
Deep tillage	Tractor 4x4 (120-199kW) 7 bottom reversible plough Grooved rollers up to 5m	62.34 68.36 111.01	1.1	265.88
Hauling	Tractor 4x4 (80-99 KW) Tooth harrow over 9m	32.26 26.85	0.3	17.73
Fertilizing 0.21-0.3 t/ha trans.included	Self-propelled fertilizer spreaders	97.17	0.35	34
Soil preparation by combinators	Tractor over 200kW Combinators, swath over 6m	71.59 89.66	0.4	64.5
Sowing	Tractor 4x4 (80-99 KW) Universal drill machine	32.26 137.38	0.35	59.37
Hemp mowing	Tractor 4x4 (70-79 kW) Moving machine	36.62 78.88	0.7	80.85
Hemp compressing	Tractor 4x4 (80-99 KW) Baler	32.26 95.24	0.6	76.5
Transport	Tractor 4x2 (60-69 kW) Tipping trailer	24 44.66	1.4	96.12
Stubble tillage	Tractor 4x4 (120 -199kW) Plate cultivator	62.34 30.09	0.35	32.35
Briquetting 1	BRISUR 800 Crusher+separator HIMMEL 22	11.61	15.54	173.14
Briquetting 2	BRIKSTAR 200 Crusher + separator	4.46	39.9	178.15

*0.1 r * 0.15 r repetitiveness



Average daily temperature for growing season (May – October) 2009



Average daily temperature for growing season (June– March) 2012

Source: The meteorological station of CZU

Table 2. Values of repair constant and repair exponent used in the calculation of accumulated repair costs for various types of machines

Machine type	Av field speed, (km/h)		Estimated life, (hrs)	Total life repairs, % of list price	Accumulated repair cost index	
	Typical	Range			Repair constant	Repair exponent
Tractors and Transport						
Two-wheel drive			10 000	120	0.012	2.0
Four-wheel drive & Crawler			10 000	100	0.010	2.0
Trailer			3 000	80	0.19	1.3
Tillage						
					0.43	1.8
Mouldboard	7.0	5.0 -	2 000	150	0.18	1.7
plough		10.0	2 000	60	0.18	1.7
Heavy-duty disc	7.0	5.5 -	2 000	60	0.38	1.4
Tandem disc		10.0	2 000	100	0.30	1.4
harrow	6.5	5.0 -	2 000	80	0.30	1.4
Chisel plough		10.0	2 000	80	0.16	1.3
Field cultivator	7.0	6.5 -	2 000	40	0.23	1.4
Spring tooth		10.5	2 000	60	0.22	2.2
harrow	9.0	5.0 -	2 000	100	0.36	2.0
Roller-packer		13.0	1 500	80		
Rotary hoe	9.0	5.0 -				
Rowcrop cultivator		10.0				
Rotary cultivator	10.0	7.0 -				
		12.0				
	11.0	8.0 -				
		16.0				
	5.5	4.0 - 8.0				
	5.0	2.0 - 7.0				
Establishment						
Fertilizer spreader	7.0	5.0 - 8.0	1 200	120	0.95	1.3
Grain drill	6.5	4.0 -	1 200	80	0.54	2.1
Crop sprayer		10.0	1 500	70	0.41	1.3
	10.5	5.0 -				
		11.5				
Harvesting						
Combine harvester:						
Trailed	5.0	3.0 - 6.5	2 000	90	0.18	2.3
Self-propelled	5.1	3.0 - 6.5	2 000	50	0.12	2.1
Mower	8.0	6.5 - 11.5	2 000	150	0.46	1.7
Mower conditioner	7.0	5.0 - 10.0	2 000	80	0.26	1.6
Side delivery rake	7.1	6.5 - 8.0	2 000	100	0.38	1.4
Baler	5.5	4.0 - 8.0	2 000	80	0.23	1.8
Big bale baler	5.6	5.0 - 8.0	2 000	80	0.23	1.8
Forage harvester:						
Trailed	4.0	2.5 - 4.0	2 000	80	0.23	1.8
Self-propelled	5.0	2.5 - 10.0	2 500	60	0.12	1.8
Forage blower			2 000	50	0.14	1.8
Sugar beet	5.0	4.0 - 8.0	2 500	70	0.19	1.4
harvester	3.0	2.5 - 6.5	2 500	70	0.19	1.4
Potato harvester						

Source: Havrland