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COST AND BENEFIT OF ENERGETIC PLANTS - CHALLENGES FOR ENVIRONMENT FRIENDLY MANAGEMENT

KOSZTY I KORZYŚCI WYKORZYSTANIA ROŚLIN ENERGETYCZNYCH - WYZWANIA DLA PRZYJAZNEGO ZARZĄDZANIA ŚRODOWISKIEM

Abstract: Biomass energy has been recognized as one of the most promising and most important renewable energy sources in near future. It was emphasized that besides of woody plant species as energetic plants can be also used both crops (mainly maize, rapeseed, sunflower, soybean, sorghum, sugarcane) and non-food plants (e.g. switchgrass, jatropha, algae). **Energetic plant** was characterized as a plant grown as a low cost and low maintenance harvest used to make biofuels, or directly exploited for its energy content (heating or electric power production). Moreover, by-products (green waste) of crops and non-food plants can be also used to produce biofuels. It was stressed that European production of biodiesel from energy crops has grown steadily in the last decade, principally focused on rapeseed used for oil as a substance in FAME (*fatty acid methyl ester*) production. Similar tendency was observed for bioethanol (as a biocomponent in gasoline) prepared mainly from maize or cereals. At present bioethanol and biodiesel primarily produced from the crops (maize and rapeseed) are used in the traffic. However, in the past these crops were used only as a food. Consequently, a new ethical problem appeared: discrepancy between utilization of maize and rapeseed as a food or as an alternative source of energy. New biotechnological approach showed that energetic plants have also significant application for environment friendly management, mainly in phytoremediation technology. Phytoremediation was presented as a cleanup technology belonging to the cost-effective and environment-friendly biotechnology. Thus several types of phytoremediation technologies being used today were briefly outlined.

Keywords: alternative energy source, bioethics, biofuels, energetic plants, environment, phytoremediation

Introduction

In the worldwide scale biomass is the greatest source of renewable energy (in detail see [1]). The amount of energy stored in the biomass is approximately 7.5-times greater than is global share (46%) responded to biomass [2]. Under condition of Slovakia it is actual to use for energetic purposes forest biomass including energetic wastes from wood-processing industry as well as food industry and waste biomass from industrial and communal field. The use of forest biomass for energetic purposes is relatively favourable. It is mainly residual wood and wood mass which could not be used for other purposes (residua after timber production, smallwood of trees, salvage felling timbre, etc.). For combustion are suitable wood pieces, wood chips, briquettes or pellets made from forest biomass. It was shown that very perspective is mainly cultivation of energetic forest coppices (willow, poplar, and black locust tree). Wood-working industry represents app. 40% portion from total technically utilizable potential of biomass (wastes originated from mechanical processing of wood, filings, bark). Biomass from the agriculture (straw, plant residues) arised either from cultivation of crops (maize, cereals, rapeseed) or from food industry (pressing of oilseeds and fruits, cutting of fruit trees or vine) (in details see [3]).

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Biomass as a source of renewable energy

According to some authors (eg [4]) biofuels are likely more ecological than conventional fossil fuels what could be a substantial argument mainly from the aspect of world-wide concentration increase of greenhouse gases, mainly CO_2 [5]. Further arguments supporting the use of biofuels are: continually increasing price of liquid fossil fuels, the use of soils with lower bonita for cultivation of technical crops, overproduction of crops with lower quality which could not be used as a food. At present extraordinary attention is devoted to the study of exploitation of both, second generation biofuels (produced from technical crops, which could not be used as a food, as well as from biomass wastes) [6, 7] and third generation biofuels (produced from transgenic - GM - energetic plants or from algae). However, the most important biomass in Europe as a source of renewable energy is presented by fast-growing trees like willow, poplar and to some extent alders (cf. [8]).

Energetic plants

In general, energetic plants - EP (energy crops) are the plants grown as a low cost and low maintenance harvest used to make biofuels, or directly exploited for its energy content (heating or electric power production). According to Weger [9] for the choice of suitable energetic plants following criteria could be considered: a) high biomass production (mass, volume, energy content, b) manageability of cultivation (effective cultivation techniques), c) biomass suitability for biofuel production (with respect to different criteria for solid, liquid and gaseous fuels, respectively), d) economy of biomass production (at a given economic conditions and financial subvention); e) environmental aspects (eg greenhouse gases balance, invasive plant species, etc).

There are many species used as EP (eg [10]). Some of them are herbs (eg *Zea mays*, *Brassica napus*, *Triticum aestivum*, *Helianthus annuus*, *Helianthus tuberosus*, *Sorghum bicolour*, *Miscanthus* sp., *Jatropha curcas*), shrubs or trees (eg *Populus* sp., *Salix* sp., *Alnus glutinosa*, *Ailanthus altissima*, *Ulmus montana*). Since cultivation of the most of above mentioned herbs is in general very well known, therefore in the following text our attention will be paid to cultivation of energetic trees - energy forestry. Basis for this approach is sustainable tree biomass production presented eg by Andersson [11].

Energy forestry

Energy forestry is a form of forestry in which a fast-growing shrubs or trees are grown specifically to provide biomass or biofuel for heating or power generation [cf. 12]. There are two forms of energy forestry: **short rotation forestry (SRF)** and **short rotation coppice (SRC)** (in detail see [10, 13]). The first one are species like alder, ash, birch and poplar grown for 8 to 20 years before the first harvest. SRC uses high yield varieties of poplar and willow grown for 2 to 5 years before the first harvest. This woody solid biomass can be used in applications such as district heating, electric power generating stations, alone or in combination with other fuels [8].

Energetic plants and climatic changes

Anthropogenic factors continue to elevate atmospheric CO_2 concentration, which on average has already exceeded 377 ppm in the year 2006 [14] which shows a substantial increase from 280 ppm in the year 1750 (IPCC 2001). The change in atmospheric CO_2 is correlated to the 0.8°C increase in global average surface temperature in the past century, and the warming rate of about 0.2°C per decade [15]. Biomass can be used to produce C-neutral fuels to power for transportation industry [16]. Biomass fuels are C-neutral because they release recently-fixed CO_2, which does not shift the C-cycle. Biomass may generate the same amount of CO_2 as fossil fuels per unit C, but every time a new plant grows it removes that same CO_2 from the atmosphere [10].

Causes of both short-term and long-term climatic changes on the earth are discussed for many years (eg Kyoto Protocol 1997, summit OSN, Bali, 2007). Nowadays 9 milliards tonnes of carbon are emitted from anthropogenic sources into atmosphere [17]. We suppose that high greenhouse gases concentration in atmosphere will increase temperature of our planet, mainly in the north part of hemisphere.

Besides the most important greenhouse gas - CO_2 the further greenhouse gas - N_2O outcoming from fertilization (especially rapeseed) is intensively discussed [18]. This gas was classified as a third most important greenhouse at all. Its global warming potential (GWP) is 296x higher than GWP of CO_2. [5]. It could be supposed that N_2O emission will increase in connection with higher cultivation area of rapeseed.

Invasive and genetically modified energetic plants - potential risk for the environment?

Several biofuel crops, which many countries are promoting as an alternative to fossil fuels, have many traits in common with invasive species [19, 20]. These species fulfil characteristics of an ideal biomass crop: low energy into maintenance relative to the production of energy-rich biomass; efficient use of irradiance, water and nutrients; C_4 photosynthesis; nutrient translocation into storage organs during the non-growing season; and perennial growth. Domestication of non-native crops, in fact, is considered one of the main pathways of biological invasions [21]. In particular, according to Barney and DiTomaso [20], biofuel feedstock can survive in conditions that mimic natural habitat.

The enhancement of environmental tolerance in GM energetic plants likely will increase the risk of invasion into surrounding environments. Similarly, enhancement of aboveground biomass production via biotechnology could allow such cultivars to be more competitive with native vegetation or other cultivated crops. Genetic modification can change the phenotype or physiology of a plant species sufficiently to lead to alterations in plant-plant interactions and ecological functions. Thus, it is important to recognize that, like non-native species, even native plants, if modified would pose an unknown risk of becoming invasive [22]. Based on above-mentioned facts it should be beneficial to perform genotype-specific pre-introduction screening for a target region, which consists of risk analysis, climate-matching modelling, and ecological studies of fitness responses to various environmental scenarios. Such screening procedure will provide reasonable assurance that economically beneficial biofuel crops will pose a minimal risk of damaging native and managed environment [20].

Biofuels - environment friendly approach

As it has already been mentioned biofuel is renewable fuel that can be prepared from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulates, carbon monoxide, hydrocarbons, and air toxics. In spite of these facts progress in biofuel use is nowadays still discussed.

First-generation biofuels rely on food plant species (crops) as their feedstock. Corn, soy, rapeseed and sugarcane all have readily accessible sugars, starches and oils. Thus to change them into biofuels simply involves either fermenting the sugars or transform the fatty oils through transesterfication. **Second-generation biofuels** use lignocellulosic biomass as feedstock (mainly wood, ie trees), non-food plants like switchgrass (*Panicum virgatum*) and agricultural residue (as well as other organic wastes) such as corn stalks. Rather than improving the fuel-making process, **third-generation biofuels** seek to improve the feedstock. Designing oilier crops, for example, could greatly boost yield. Scientists (geneticists) have designed poplar trees (ie GM poplars) with properties to make them easier to process. Researchers have already mapped the genomes of sorghum and corn, which may allow genetic agronomists to change the genes controlling oil production. Thus, third generation biofuels are carbon neutral when consumed meaning that the crops consume the same amount of carbon from the atmosphere as they will release when combusted. This is done through GM and nowadays it is not yet commercially available. **Fourth-generation technology** combines genetically optimized feedstocks, which are designed to capture large amounts of carbon, with genomically synthesized microbes, which are made to efficiently make fuels. Key to the process is the capture and sequestration of CO_2, a process that renders fourth-generation biofuels a “carbon negative” source of fuel (in detail see [23]).

The major benefit of biofuels is the potential to reduce net CO_2 emissions to the atmosphere. Enhanced C management may make it possible to take CO_2 released from the fossil C cycle and transfer it to the biological C cycle to enhance food, fiber, and biofuel production as well as sequester C for enhancing environmental quality [10].

Phytoremediation - cost-effective green biotechnology

Environmental pollution with xenobiotics including toxic metals is still serious global problem. Development of phytoremediation technologies for the plant-based clean-up of contaminated substrates is therefore of significant interest. Phytoremediation is environment-friendly and cost-effective green technology for the removing of toxic metals and organic pollutants from the environment using the some species of the plants. There are several types of phytoremediation technologies currently available for clean-up of both contaminated soils and water. The most important of them are **phytoextraction**, **rhizofiltration**, **phytostabilization**, **rhizodegradation**, **hydraulic control and phytorestauration** [24, 25].

The most effective but also technically the most difficult phytoremediation technology is phytoextraction involving the cultivation of metal-tolerant plants that concentrate soil contaminants in their aboveground tissues. At the end of the growth period, plant biomass is harvested, dried or incinerated, and the contaminant-enriched material is deposited in a special dump or added into a smelter. The energy gained from burning of the biomass could support the profitability of this technology, if the resultant fumes can be cleaned appropriately. For phytoextraction to be effective, the dry biomass or the ash derived from above ground tissues of a phytoremediator crop should contain substantially higher concentrations of the contaminant than the polluted soil [26].

It should be stressed that from above-mentioned phytoremediation technologies the most frequent practical application has phytoextraction which has been growing rapidly in popularity world-wide for the last twenty years. In generally, this process has been tried more often for extraction of toxic metals than for organic substances. A living plant may continue to absorb contaminants until it is harvested. After harvest a lower level of the contaminant will remain in the soil, so the growth/harvest cycle must usually be repeated through several crops to achieve a significant cleanup. After the process, the cleaned soil can support other vegetation.

Energetic plants vs bioethics aspects

In connection with the increasing trend of biofuel use an important ethical problem occurred - perplexity whether crops (eg maize, cereals, potatoes, rapeseed, and sunflower) could be used exclusively for alimentary purposes or also as an alternative energy source. Astyk [27] published twelve ethical principles which describe all actual aspects (both positive and negative) of biofuels. Serious factor also is the increase of the soil portion designated for cultivation of technical crops at the expense of forests and natural vegetation, what could be reflected in the biodiversity decline. These assumptions evoked negative reflection in the world, too. Therefore, acceptance of fundamental principles of bioethics is needed.

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References

[1] Flach B. et al: Netherlands-Germany EU-27/ EU-27 Biofuels Annual. Annual Report 2009. Gain Report Number: NL9014, Date 6/15/2009 http://gain.fas.usda.gov/Recent%20GAIN%20Publications/General%20Report_The%20Hague_Netherlands-Germany%20EU-27_6-15-2009.pdf

[2] Jasiulewicz M. and Jasiulewicz R.: *Biomass from energetic plants as a renewable energy source.* Stow. Ekonom. Rol. Agrob., 2009, **7**, 48-51.

[3] Kisely P. and Horbaj P.: *Possibility for the biomass utilisation in Rožňava region*. Contribution presented at the Workshop "Preparation of biomass as a fuel for small heating systems for biomass - local solutions for local Requirement". Kysucký Lieskovec, June 19-20, 2006. http://www.biomasa.sk/files/jrccleanweb.pdf

[4] Kráľová K. and Masarovičová E.: *Minimalisation of the risks for environment at rapeseed cultivation for use as biofuels*. [in Slovak]. [In:] A. Manová, F. Čacho (ed.): Proc. 28th Conference of Industrial Toxicology 08. Tatranská Štrba, June 18-20, 2008, 311-315.

[5] Crutzen P.J., Mosier A.R., Smith K.A. and Winiwarter W.L.: *N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels*. Atmos. Chem. Phys. Discuss., 2007, **7**, 11191-11205.

[6] Carere C.R., Sparling R., Cicek N. and Levin D.B.: *Third generation biofuels via direct cellulose fermentation*. Int. J. Mol. Sci., 2008, **9**, 1342-1360.

[7] Hertwich E.G. and Zhang X.: *Concentrating-solar biomass gasification process for 3rd generation biofuels.* Environ. Sci. Technol., 2009, **43**, 4207-4212.

[8] Perttu K.L.: *Environmental justification for short-rotation forestry in Sweden.* Biomass Bioenergy, 1998, **15**, 1-6.

[9] Weger J.: *Energy crops in Czech Republic and in EU* (In Czech). 2007. http://www.vukoz.cz/vuoz/biomass.nsf/pages/eplodiny.html

[10] Johnson J.M.F., Coleman M.D., Gesch R., Jaradat A., Mitchell R., Reicosky D. and Wilhelm W.W.: *Biomass-bioenergy crops in the United States: A changing paradigm.* Amer. J. Plant Sci. & Biotech. 2007, **1**, 1-28. http://www.globalsciencebooks.info/JournalsSup/images/SF/AmJPSB_1(1)1-28.pdf

[11] Andersson F.O., Ågren G. and Führer E.: *Sustainable tree biomass production*. Forest Ecol. Manage., 2000, **132**, 51-62.
[12] Perttu K.L. and Kowalik P.J.: Modelling of energy forestry: growth, water relations and economics. PUDOC, Wageningen 1989, 198 pp.
[13] Sims R.E.H., Maiava T. G. and Bullock B.T.: *Short rotation coppice tree species selection for woody biomass production in New Zealand*. Biomass Bioenergy, 2001, **20**, 329-335.
[14] Blasing T.J. and Smith K.: *Recent Greenhouse Gas Concentrations*. Oak Ridge National Laboratory, United State Department of Energy. Available, 2006. http://cdiac.ornl.gov/pns/ current_ghg.html
[15] Hansen J., Sato M., Ruedy R., Lo K., Lea D.W. and Medina-Elizade M.: *Global temperature change*. Proc. Natl. Acad. Sci. USA, 2006, **103**, 14288-14293.
[16] Hoffert M.I., Caldeira K., Benford G., Criswell D.R., Green C., Herzog H, Jain A.K., Kheshgi H.S., Lackner K.S., Lewis J.S., Lightfoot H.D., Manheimer W., Mankins J.C., Mauel M.E., Perkins L.J., Schlesinger M.E., Volk T. and Wigley T.M.L.: *Advanced technology paths to global climate stability: energy for a greenhouse planet*. Science, 2002, **298**, 981-987.
[17] Balajka J., Lapin M., Minďáš J., Šťastný P. and Thalmeinerová D.: *Fourth National Report of SR about State of Climate and Report about Attained Progress at Fulfilling Kyoto Protocol.* (in Slovak). Ministry of Environment of Slovak Republic and Slovak Institute of Hydrometeorology, Bratislava, Slovak Republic. 2005.
[18] Mosier A.R., Duxbury J.M., Freney J.R., Heinemeyer O. and Minami K: *Nitrous oxide emissions from agricultural fields: Assessment, measurement and mitigation*. Plant Soil, 1996, **181**, 95-108.
[19] Raghu S., Anderson R.C., Daehler C.C., Davis A.S., Wiedenmann R.N., Simberlof D. and Mack R.N.: *Adding biofuels to the invasive species fire?* Science, 2006, **313**, 1742.
[20] Barney J.N. and DiTomaso J.M.: *Non-native species and bioenergy: are we cultivating the next invader?* BioScience, 2008, **58**, 64-70.
[21] Reichard S.H. and White P.: *Horticulture as a pathway of invasive plant introductions in the United States*. BioScience, 2001, **51**, 103-113.
[22] DiTomaso J.M., Barney J.N. and Fox A.M.: *Biofuel Feedstocks: The Risk of Future Invasions.* CAST Commentary QTA 2007-1, CAST, Ames, Iowa, 2007.
[23] Rubens C.: *WTF Are Fourth-Generation Biofuels?* 2008. http://earth2tech.com/2008/03/04/wtf-are-fourth-generation-biofuels/
[24] Meagher R.B.: *Phytoremediation of toxic metal and organic pollutants.* Curr. Opion. Plant Biol., 2000, **3**, 153-162.
[25] Masarovičová E. and Kráľová K.: *Medicinal plants - past, nowadays, future*. Acta Hort., 2007, **749**, 19-27.
[26] Krämer U.: *Phytoremediation: novel approaches to cleaning up polluted soils*. Curr. Opin. Biotech., 2005, **16**, 133-141.
[27] Astyk S.: *Ethics of biofuels*. Energy Bull., 28.12.2006. http://www.energybulletin.net/node/24169

KOSZTY I KORZYŚCI WYKORZYSTANIA ROŚLIN ENERGETYCZNYCH - WYZWANIA DLA PRZYJAZNEGO ZARZĄDZANIA ŚRODOWISKIEM

Abstrakt: Energia biomasy jest uznana za jedno z najbardziej obiecujących i najważniejszych odnawialnych źródeł energii. Podkreślono, że oprócz gatunków roślin drzewiastych, jako rośliny energetyczne mogą być również wykorzystywane uprawy (głównie kukurydzy, rzepaku, słonecznika, soi, sorgo, trzciny cukrowej) i inne rośliny niespożywcze (np. proso, jatrofa, glony). Uprawa i zbiór **roślin energetycznych** wymaga niewielkich kosztów, a wykorzystuje się je do produkcji biopaliw lub bezpośredniego uzyskania energii (ogrzewanie lub produkcja energii elektrycznej). Ponadto, produkty uboczne upraw (odpady zielone) i inne rośliny niespożywcze mogą być także wykorzystywane do produkcji biopaliw. Podkreślono, że europejska produkcja biodiesla z roślin energetycznych stale rośnie w ostatnim dziesięcioleciu, koncentrując się głównie na oleju rzepakowym stosowanym w produkcji FAME (estry metylowe kwasów tłuszczowych). Podobne tendencje zaobserwowano w przypadku bioetanolu (jako biokomponentu benzyny), otrzymywanego przede wszystkim z kukurydzy i zbóż. Obecnie bioetanol i biodiesel, wytwarzane głównie z kukurydzy i rzepaku, są stosowane w transporcie. Natomiast w przeszłości rośliny te były używane tylko jako żywność. W konsekwencji pojawiły się nowe problemy etyczne wynikające z rozbieżność między wykorzystaniem kukurydzy i rzepaku jako żywności lub jako alternatywnego źródła energii. Nowe podejście biotechnologiczne pokazuje, że rośliny energetyczne mają również duże znaczenie dla przyjaznego zarządzania środowiskiem, szczególnie w fitoremediacji. Oczyszczanie za pomocą fitoremediacji jest uważane za technologię oszczędną i przyjazną dla środowiska. W skrócie zaprezentowano niektóre z obecnie wykorzystywanych rodzajów fitoremediacji.

Słowa kluczowe: alternatywne źródła energii, bioetyka, biopaliwa, rośliny energetyczne, środowisko, fitoremediacja