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Elena MASAROVIČOVÁ[*1], Katarína KRÁĽOVÁ[*] and Matúš PEŠKO[*]

ENERGETIC PLANTS - COST AND BENEFIT

ROŚLINY ENERGETYCZNE - KOSZTY I KORZYŚCI

Abstract: Biomass energy has been recognized as one of the most promising and most important renewable energy sources in the near future. In some countries of EU (like Slovakia and Poland), renewable energy sources cover only around 6% of energy demand, whereby energy gained from biomass does not extend 3% in the overall energy production. Hence European Commission has already supported all potential activities related to alternative sources of energy, whereby biomass showed crucial position. 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 (eg switchgrass, jatropha, algae). In general, **energetic plant** is 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 methylester) production. Similar tendency was observed for bioethanol (as a biocomponent in gasoline) prepared mainly from maize or cereals. Support of biofuel production reflected response of many governments of EU countries to the long-term climatic changes and continuously increasing price of crude oil as well as recently observed excess of cereals. At present bioethanol and FAME 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. It should be emphasize that large resources of biomass energy are related also to forestry residues, forestry fuel wood and fast growing woody plants, mainly willow, poplar, black locust and European alder. The first two mentioned species have already great tradition for their plantation cultivation. In above-mentioned context, 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 [1]. The amount of energy stored in the biomass is approximately 7.5-times greater than is global

[*] Faculty of Natural Sciences, Comenius University Bratislava, Mlynská dolina, SK-84215 Bratislava, Slovakia
[1] Corresponding Author: masarovicova@fns.uniba.sk

energy consumption. From the total technically exploitable energetic potential the greatest share responded to biomass [eg 2]. Under condition of Slovakia it is actual to use for energetic purposes forest biomass including energetic coppices, agricultural biomass, 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 timbre felling, 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, black locust tree). Wood-working industry represents approx. 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]).

In the past few years, primary energy production from biomass in the EU has been steadily increasing to 66.4 million Mg of crude oil equivalent in 2007. Wood-based biomass is the main source for bioenergy in Europe, followed by waste and agricultural-based biomass. Most of the biomass is used for heat, and to a lesser extent, in combined heat and power (CHP) applications. In the EU the main producers are countries with large territories and large forestry resources such as France, Sweden, Germany, Finland and Poland. Biomass will play an increasingly important role in the EU energy market with respect to the 20% target for renewable use by 2020 and in the future reduction of CO_2 emissions in Europe [1].

Biomass as a source of renewable energy

Compared with other countries energetic use of biomass in Slovakia nowadays expressively falls behind to its potential energetic, economic and environmental possibilities. The portion of assessing biomass on total consumption of primary fuel-energetic sources is only 1%. However, considering all above-mentioned facts the most perspective approach is the use of biofuels (biodiesel and gasoline with bioethanol) on the basis of plant biocomponents (fatty acid methyl ester [FAME] from rapeseed or sunflower oil in biodiesel; ETBE, (ethyl *tert*-butyl ether) or bioethanol in gasoline). Biofuels are likely more ecological than conventional fossil fuels [4] what could be a substantial argument mainly from the aspect of worldwide 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 quality class 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, 9]).

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). If carbohydrate content is desired for the production of biogas, whole-crops such as maize, Sudan grass, millet, white sweet clover and many others, can be made into silage and then converted into biogas [6, 7]. Energy is generated by burning plants grown for this purpose, often after the dry matter is pelletized. EP are used for firing power plants, either alone or co-fired with other fuels. Alternatively they may be used for heat or combined heat and power production. EP are typically densely planted, high yielding species cultivated for the purpose of producing (non-food) energy - burning wood or biofuel. According to Weger [10] 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 [11]). Some of them are herbs (eg *Zea mays, Brassica napus, Triticum aestivum, Helianthus annuus, Helianthus tuberosus, Sorghum bicolor, Miscanthus* spp., *Jatropha curcas*), shrubs or trees (eg *Populus* spp., *Salix* spp., *Alnus glutinosa, Ailanthus altissima, Ulmus montana*). Since cultivation of the most of above-mentioned herbs are 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 et al [12].

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 they grow specifically to provide biomass or biofuel for heating or power generation [cf. 13]. There are two forms of energy forestry: **short rotation forestry (SRF)** and **short rotation coppice (SRC)** (in detail see [11, 14]). 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, 9].

In forestry, plantations of trees are typically grown as an even-aged monoculture for timber production, as opposed to a natural forest, where the trees are usually of diverse species and diverse ages. A plantation is not a natural ecosystem. Plantations are also sometimes known as "man-made forests" or "tree farms", though this latter term more typically refers to specialist tree nurseries which produce the seedling trees used to create plantations. More generally, a plantation is forest land where trees are grown for commercial use, most often in a planted forest, but may also be in a naturally regenerated forest. In the United States, the term “Tree Farm” is a trademark of the American Tree Farm system, a third party verification system for certifying sustainable forestry. The

American Tree Farm system dates back to 1941 as a program to improve forestry practices on farms. The term tree farm is also sometimes used to describe the sale of live trees for landscaping. A plantation is usually made up of fast-growing trees planted either to replace already logged forests or to substitute for their absence. Plantations differ from natural forests in several ways: (a) plantations are usually monocultures - the same tree species is planted in rows across a given area, whereas a conventional forest would contain far more diverse tree species; (b) plantations may include introduced tree species not native to the area, including unconventional types such as hybrid trees and genetically modified (GM) trees. Since the primary interest in plantations is to produce wood or pulp, the types of tree found in plantations are those that are best-suited to industrial applications. For example, pine or spruce are widely used because of their fast growth rate and are good for paper and timber production; (c) plantations are always young forests. Typically, trees grown in plantations are harvested after 10 to 60 years, rarely up to 120 years. This means that the forests produced by plantations do not contain the type of growth, soil or wildlife typical of old-growth natural forest ecosystems. Most conspicuous is the absence of decaying dead wood, a very important part of natural forest ecosystems [cf. 8, 9].

SRF plantation for biomass as an alternative energy is stem production followed either by replanting or by coppicing. Single stem systems utilise a range of hardwoods and softwoods, whereas a coppice system utilises hardwood genera, primarily *Salix* and *Populus*. In order to maximise the stored chemical energy in the biomass (in terms of GJ/ha/yr), a SRF coppice grower should ideally plant tree species with vigorous growth and coppicing ability best suited to the local conditions. When grown at relatively high densities as compared with traditional plantation forests, this would result in high mean annual increments of biomass. Although many parameters are important determinants of the suitability of a tree species grown for SRF, total biomass yield (in terms of megagrams of aboveground dry matter per hectare per year, Mg d.m./ha/yr), is considered to be the most important as it indicates the ability to produce actual marketable fuelwood product. Biomass yields vary with species, age of root stock, population density, length of rotation and time of harvest [eg 8, 11]. Typically the yield of a first coppice *Eucalyptus* harvest can be double that of the single stem harvest, with the second coppice harvest yielding around 150%, and the third coppice harvest yielding 100%, ie similar to that of the establishment crop harvest. Similarly, reported yields of *Salix viminalis* were 5.7 Mg d.m./ha/yr after 2-yr growth in the establishment rotation compared with 8.3 Mg d.m./ha/yr following the first 2-yr coppice rotation.

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 [15] 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 [16]. Biomass can be used to produce C-neutral fuels to power for transportation industry [17]. 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 [11].

Support of biofuels reflected response of energetic plants production to the long-term climatic changes in connection with quantitative and qualitative parameters of bio-components in biofuel. In agricultural practice it was recognized that the screening of new varieties of rapeseed (for biodiesel) or maize (for bioethanol) should be done in the relationship to the actual or long-term climatic changes with respect to resistance against the drought and temperature stress. This fact is a challenge for agronomists, plant physiologists and production ecologists to solve the above-mentioned topic. Selection of growth parameters and climatic factors which are the most important for formation of plant biomass and seed production (eg maize and rapeseed) will be needed.

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 Mg of carbon are emitted from anthropogenic sources into atmosphere [18]. We suppose that high greenhouse gases concentration in atmosphere will increase temperature of our planet, mainly in the north hemisphere.

Besides the most important greenhouse gas, CO_2 the further greenhouse gas - N_2O outcoming from fertilization (especially rapeseed) is intensively discussed [19]. 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.

In the last century in Slovakia increase of mean year air temperature approx. about 1.1°C and decrease of year sum of atmospheric rainfall about 5.6% were observed. Intensive decrease of both relative air humidity (to 5%) and snow cover in the whole area of Slovakia were observed. These observations confirmed that mainly southern part of Slovakia is gradually dried - potential evapotranspiration increased and soil humidity decreased; changes in global irradiance were not found [18].

In actual agriculture it should be focused to maintenance management, which is system with natural soil recovery and without environment destructions. This approach will need a new climatic regionalization and new structure of crops to use effectively all natural sources - mainly irradiance balance and water regime. Geneticists should focus to find new genotypes and hybrids with higher resistance to abiotic and biotic stresses.

The EU Energy and Climate Change Package (CCP) was finally adopted by the Council on April 6, 2009. The Renewable Energy Directive (RED), which is part of this package, was completed in December 2008 and was entered in force on June 25, 2009. This package includes the „20/20/20" goals for 2020 [1]:

- 20% reduction in greenhouse gas (GHG) emissions compared with the levels of the year 1990
- 20% improvement in energy efficiency compared with current forecasts for the year 2020
- 20% share for renewable energy in the EU energy mix (consumption). Part of this 20% share is a 10% minimum target for renewable energy consumed in transport to be achieved by all Member States (most, but not all of this 10% will come from increased biofuel use).

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 [20, 21]. 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 [22]. In particular, according to Barney and DiTomaso [21], 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 [23].

On the other hand, as exemplified by the sterile biofuel crop miscanthus (*Miscanthus* × *giganteus*), a lack of seed production can decrease the risk of escaping cultivation dramatically [24]. Sterile cultivars can decrease the likelihood of biofuel species escaping from production fields. However, it should be stressed that *Miscanthus* × *giganteus* is an allopolyploid that does not produce viable seed and reproduces vegetatively. Therefore allopolyploidy does not guarantee continued sterility and vegetative propagation is often associated with invasiveness or directly contributes to it [20].

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 [21].

Biofuels - environment friendly approach

Practical application of biofuels in the last decade arised from crude oil crisis as well as from global rise of temperature connected with higher production of greenhouse gases, mainly CO_2. Thus promotion of the production and use of biofuels could contribute to a reduction in energy import dependency and in emissions of greenhouse gases. Moreover, biofuels, in pure form or as a blend, may in principle be used in existing motor vehicles and utilized by current motor vehicle fuel distribution system. The blending of biofuel with fossil fuels could facilitate a potential cost reduction in the distribution system in the EU. Some countries are already using biofuel blends of 10% and higher. The Commission Green Paper „Towards a European strategy for the security of energy supply" sets the objective of 20% substitution of conventional fuels by alternative fuels in the road transport sector by the year 2020 (in detail see [25]).

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 transesterification. **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. Using specially designed microorganisms, the feedstock's tough cellulose is broken down into sugar and then fermented. Alternatively, a thermochemical route can be taken whereby the biomass is gasified and then liquefied, a process known as „biomass-to-liquid" (BtL). 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 content 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. However, the weak link is carbon capture and sequestration technology, which continues to elude the coal industry (in detail see [26]). For carbon negative crop the amount of carbon consumed during the crops growth is bigger than the amount released when combusted in an engine. This is made possible through genetic engineering of the crops. Taking into account all of the issues lately with global warming fourth generation biofuels become a very attractive option as a renewable energy source. A carbon negative fuel will reduce carbon levels in the atmosphere allowing us to combat global warming as we also shift to a renewable fuel [27].

Considering the above-mentioned facts from the aspect of biomass utilization for biofuel production significant possibilities for applied physiological and production research of some crops, eg rapeseed [28-30], sunflower [31], soya, amaranthus (FAME, addition to biodiesel), maize, potatoes, barley (ETBE and bioethanol addition to gasoline) are shaped. From cultivation and climatic aspect the most perspective for Slovakia are rapeseed (FAME) and maize (ETBE and bioethanol), technological processing of which is realized by companies Enviral and Meroco in factories for FAME and bioethanol production. Annual output of 120 millions dm^3 of bioethanol and 100 000 Mg of FAME are challenge for achievement of the goal - up to 2010 to enhance the portion of biofuels in conventional fuels from actual 4.75% to 5.75%. It will be necessary to secure the presented biethanol production predominantly from self-production. However, the increased demand for maize and rapeseed could not be secured by raising of cultivation area but by increasing yield per hectare. Slovakia with mean yield per hectare corresponding to 6 Mg of maize falls behind countries without tradition in maize cultivation, such are Czech Republic or Poland. For comparison: in neighbouring Austria achieve yearly on average 10 Mg maize per hectare. Similar situation is also in the case of FAME. At present 65% of FAME demand realizes Slovnaft from the import. After recent start of the plant in Leopoldov in the future the majority of FAME could originate from inland production [25].

With respect to the fact, that assortment of actually utilized rapeseed and maize cultivars (which is available at Central and Testing Institute in Agriculture in Bratislava, Slovakia) was obtained on the basis of biomass of vegetation organs as well as on the quantity and quality of fruits (seed of rapeseed, maize grain) it is necessary to complete the missing physiological parameters which will serve as a base for economic yield of crops. Based on these data it will be possible to select and advise such cultivars of rapeseed and maize which will be suitable for cultivation also from the aspect of on the long-term changing climatic conditions of Slovakia.

In the agricultural experience it was shown that in respect to climatic changes in Slovakia (perspective of a climate characterized with higher temperature and drought, [18]) it would be necessary to perform screening of new cultivars and lines of crops, which will be more resistant against stress induced by drought and temperature as well as against black frost in the regions where the snow cover will be not sufficient. This fact present a challenge for agronomists, plant physiologists and production ecologists to contribute to solving of this problem - to select those parameters which are the most important for the production of plant biomass and from the climatic factors to determine those which are the most important from the aspect of the influence of plant biomass production. It would be necessary to take such actions which will secure that the use of crops for technical purposes will not limit their utilization as agricultural crops.

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 [11].

According to EU Energy and Climate Change Package biofuels have to meet certain criteria to be considered for the 10% goal: They must meet the sustainability criteria, eg they must reduced GHG emissions by at least 35% compared with fossil fuels beginning autumn 2010. From the year 2017 the reduction has to be 50%, and at least 60% for new installations. Biofuels made out of ligno-cellulosic, non-food cellulosic, waste and residue materials will count double towards the goal (calculation made on energy basis), renewable electricity consumed by cars will be counted by factor 2.5. However, accoring to European Comission, biofuels may not be made from raw material obtained from land with high biodiversity value such as primary forest and other wooded land areas designated by law or by relevant competent authority for nature protection purposes, highly biodiverse grassland or highly biodiverse non-grassland. Biofuels shall not be made from raw materials produced on the land with high carbon stock such as wetlands, peatlands or continuously forested areas [1].

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 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 these: reduction of soil metal concentration by cultivating plants with a high capacity for metal accumulation in the shoots **(phytoextraction)**, adsorption or precipitation of metals onto roots or absorption by the roots of metal-tolerant aquatic plants **(rhizofiltration)**, immobilization of metals in soils by root uptake, adsorption onto roots or precipitation in the rhizosphere **(phytostabilization)**, decomposition of organic pollutants by rhizosphere microorganisms **(rhizodegradation)**, absorption of large amounts of water by fast growing plants and thus prevent expansion of contaminats into adjacent uncontaminated areas **(hydraulic control)** and re-vegetation of barren area by fast grown plants that cover soils and thus prevent the spreading of pollutants into environment **(phytorestauration)** [eg 32, 33].

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 aboveground tissues of a phytoremediator crop should contain substantially higher concentrations of the contaminant than the polluted soil [34].

Metal-tolerant species (including some of energetic plants, eg *Hordeum vulgare, Triticum aestivum, Brassica napus, Brassica juncea, Helianthus annuus, Salix* spp., *Populus* spp.) can accumulate high concentration of some toxic metals in their aboveground biomass. One subset of larger category of metallophytes are hyperaccumulators (metal extractors). However, besides hyperaccumulators the fast-growing (high-biomass-producing) plants can also be used in phytoremediation technology. In spite of lower shoot metal-bioaccumulating capacity of these species, the efficient clean-up of contaminated substrates is connected with their high biomass production. Perttu and Kowalik [35] have already recognized that it is both environmentally and economically appropriate to use vegetation filters of short rotation willow to purify waters and soils. Similarly, Aronsson et al [36] successfully used short-rotation willow coppice for remediation of wastewater.

The time it takes for plants to reduce the amount of heavy metals in contaminated soils depends on two factors: how much biomass these plants produce and their metal bioconcentration factor, which is the ratio of metal concentration in the shoot tissue to the soil [37]. The latter factor is determined by the ability and capacity of the roots to take up metals and load them into the xylem, by the mass flow in the xylem to the shoot in the transpiration stream, and by the ability to accumulate, store and detoxify metals while maintaining metabolism, growth and biomass production [38-40]. With the exception of hyperaccumulators, most plants have metal bioconcentration factors less than 1, which means that it takes longer than a human lifespan to reduce soil contamination by 50%. To achieve a significant reduction of contaminants within one or two decades, it is therefore necessary to use plants that excel in either of these two factors, eg to cultivate crops with a metal bioconcentration factor of 20 and a biomass production of 10 tonnes per hectare (Mg/ha), or with a metal bioconcentration factor of 10 and a biomass production of 20 Mg/ha [41].

As mentioned above, two possible strategies have emerged to improve the phytoextraction of heavy metals: growing plant phenotypes that are able to accumulate large concentrations of heavy metals in their aboveground parts, or using phenotypes that are able to produce high biomass with average heavy-metal concentration in their harvestable tissue. Of course, it would be desirable to combine both features and design plants that are specialized for fast growth and hyperaccumulation. This is the fundamental aim that underlies efforts to generate transgenic plants for phytoremediation. Pilon-Smits and Pilon [42] focused on the design and creation of transgenic plants for phytoremediation of metals. Other than plant growth, which depends on numerous genetic and non-genetic factors, the accumulation of heavy metals is controlled by only a few gene loci and is therefore more easily accessible for genetic manipulation [43].

It should be stressed that from above-mentioned phytoremediation technologies the most frequent practical application has phytoextraction which has been growing rapidly in popularity worldwide for the last twenty years. In general, 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.

Phytoextraction as an environment friendly method could be used for cleaning up sites that are contaminated with toxic metals. However, the method has been questioned because it produces a biomass-rich secondary waste containing the extracted metals. Therefore, further treatment of this biomass is necessary. Gasification (ie pyrolysis), which occurs under reducing conditions, was a better method than incineration under oxidizing conditions to increase volatilization and, hence subsequently recovery, of Cd and Zn from plants. It would also allow the recycling of the bottom ash as fertilizer [44]. Recovery of energy by biomass burning or pyrolysis could help make phytoextraction more cost-effective. Processing of biomass to produce energy and valuable ash in a form which can be used as ore or disposed safely at low cost. Recovery of energy by biomass burn or pyrolysis could help make phytoextraction cost effective [45].

Within the *Brassica* genus, there also exist some other species which show the tendency to accumulate high metal concentrations, and which can be characterized as metal accumulators. Some of these species grow fast and produce a high biomass. Examples are *Brassica juncea* (Indian mustard), *Brassica rapa* (field mustard) or *Brassica napus* (rapeseed) [46]. If soils, contaminated with heavy metals, are phytoremediated with oil crops (such as *Brassica* spp.), biodiesel production from the resulting plant oil could be a viable alternative to generate bioenergy. If biodiesel exhaust fumes from such rapeseed plants - specifically selected for their high toxic metal uptake capacity - will have hazardous metal emissions is virtually unknown. Further scientific research to investigate this issue is essential. It is crucial that the remediation effect of the plant will not be negated by higher toxic metal emissions of vehicles, running on biodiesel obtained from phytoremediation plants [47].

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 [48] published twelve ethical principles which describe all actual aspects (both positive and negative) of biofuels. It can be observed that the former enthusiasm was replaced by scepticism. After initial opinion that biofuels can save the mankind advice appeared that biofuels are curse of this civilization. In the laic community even such mind arised that biofuels represent a „silent tsunami” which leave behind hungry and poor people. Moreover, 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.

Conclusion

Worldwide increase of biofuel production responded not only to marked global climatic changes but also to continually increasing price of crude oil and excess of cereals in recent past. In March 2007, the leaders of EU obliged that up to year 2020 the portion of alternative energy sources will be enhanced to 20%, there of the portion of biofuels at least to 10%. Nowadays in EU countries the most important three types of biofuels occurred - gasoline with the addition of ETBE or bioethanol, biodiesel and pure plant oil (PPO). These biofuels are produced from agricultural crops which were in the past utilized only for food industry (first generation of biofuels). In connection with the increasing tendency 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. Serious fact is also the increase of the soil portion designated for cultivation of technical crops on the expense of forests and original natural vegetation, what is reflected in biodiversity decline. These findings evoked negative reflection in the world. However, it should be recognised that in the case of rapeseed, the oil can be used not only for FAME production, but rapeseed cakes as a residue after seed pressing represent a high-grade fodder for animal husbandry and the waste-straw represents staple for second generation biofuels, because by hydrolysis of polysaccharides and subsequent fermentation superior bioethanol can be prepared. Similarly, glycerol generated at FAME production (10% portion) can be utilized either as a liquid fuel, in chemical and cosmetic industry or as fodder for cattle. Designing of trees, that store significantly more carbon dioxide than is their CO_2 emission, are very perspective for production of the 'fourth generation' of biofuels. Nevertheless, with the above-mentioned biological and ethical aspects further spheres (sociological and political) of the global society are connected which is important for incoming development of the human population, too.

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ROŚLINY ENERGETYCZNE - KOSZTY I KORZYŚCI

Abstrakt: Energia biomasy jest uznana za jedno z najbardziej obiecujących i najważniejszych odnawialnych źródeł energii. W niektórych krajach Unii Europejskiej (np. Słowacja i Polska) odnawialne źródła energii pokrywają tylko około 6% zapotrzebowania na energię, przy czym uzyskana energia z biomasy nie przekracza 3% w ogólnej produkcji energii. Dlatego Komisja Europejska popiera wszystkie potencjalne działania związane z alternatywnymi źródłami energii, w których biomasa zajmuje kluczową pozycję. 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). Ogólnie rzecz biorąc, uprawa **roślin energetycznych,** wykorzystywanych do produkcji biopaliw lub bezpośredniego uzyskania energii (ogrzewanie lub produkcja energii elektrycznej), wymaga małych nakładów finansowych na jej utrzymanie i zbiór roślin. 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 jako substancja w produkcji FAME (estry metylowe kwasów tłuszczowych). Podobne tendencje zaobserwowano w przypadku bioetanolu (jako biokomponentu benzyny), otrzymywanego głównie z kukurydzy i zbóż. Wsparcie produkcji biopaliw jest reakcją wielu rządów krajów UE na długoterminowe zmiany klimatyczne i ciągle rosnące ceny ropy naftowej, a także ostatnio zaobserwowany nadmiar produkcji zbóż. Obecnie bioetanol i biodiesel, głównie wytwarzane 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: rozbieżność między wykorzystaniem kukurydzy i rzepaku jako żywności lub jako alternatywne źródła energii. Należy podkreślić, że duże zasoby energii można uzyskać z biomasy pozostałości leśnych, drewna opałowego i szybko rosnących drzew liściastych, głównie wierzby, topoli i olchy europejskiej. Uprawa pierwszych dwóch wymienionych gatunków ma już duże tradycje. Nowe podejście biotechnologiczne pokazuje, że rośliny energetyczne mają również duże znaczenie dla przyjaznego zarządzania środowiskiem, głównie w fitoremediacji, która jest przedstawiona jako technologia oczyszczania oszczędna i przyjazna dla środowiska. W skrócie zaprezentowano niektóre dziś używane rodzaje fitoremediacji.

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