MICROALGAE AS A POTENTIAL SOURCE FOR BIODIESEL PRODUCTION

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Abstract. Authors of this paper present development trends in national biofuel market, in accordance with European Union regulations, as well as the first experiences and operational-logistic issues. The review includes extensive information about potential sources for plant derivative biofuels production, like microalgae. Their main advantage is that they do not compete in food products market.

Key words: biofuels, biodiesel, microalgae

Introduction

Hydrocarbon fractions from crude oil were the basic and the only approved engine fuel in over hundred-year history of the automotive industry. As a result of the first energy crisis in the 1970s, potential to use other energy sources began to be considered. The concept of alternative fuels (including biofuels obtained from biomass) appeared then. Another world fuel crises triggered off development of technologies in the field of liquid biofuel production and use, oriented to the production of full fuel-energy substitutes satisfying some additional requirements.

The main purpose for introducing biofuels is the need to increase energy safety, taking into account growing mankind demand in this field and expected deficiency of conventional energy carriers, as well as more efficient protection against substantial changes in environment condition. Currently, in Europe biofuels are defined as obtained from biomass liquid and gas fuels for combustion engines. According to its European definition specified in an applicable directive, biomass constitutes biodegradable fractions of waste products and leftovers from agricultural and food industry (including substances derived from plants and animals), forest- and derivative industries, and biodegradable fractions of municipal and industrial wastes [Biernat, Kulczycki 2009].

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Trends in biofuel market development compared to the European Union regulations

According to the Annexe no. 1 to the European Commission Communication No. 34 of 2006, COM (2006) 34 final, biofuels were divided into: liquid, gas, and other. Division of biofuels into specific generations results from the type and degree of biomaterial preparation for processing using particular technology. Those fuels have been included in the first biofuel generation (conventional biofuels), which are produced directly or indirectly from food materials through fermentation or transesterification processes.

In Poland, since the 1990s bioethanol was the first biofuel experimentally launched into the market, and then there were transesterified vegetable oils - FAME (rape-seed oil fatty acid methyl esters) [Jakóbiec 2001, Jakóbiec et al. 2005].

According to Skręt and Urzędowska [2008], due to their diverse chemical nature, these products prove substantial differences in physical and usable properties when used to power an engine, and in distribution and storage processes.

In Europe, the process of introducing biofuels into production and use was sanctioned by regulations in the directive 2003/30/EC of May 8, 2003 on supporting the use of biofuels and other renewable fuels in transport. Regulation issued by the Minister of Economy on January 22, 2009 concerning quality requirements for biofuels - ethanol petrol (E85) - allows its production and distribution in Poland. Biofuel production cost, operation reliability of combustion engines and availability of materials constitute key factors for success of actions aimed to introduce biofuels on a larger scale. There is a necessity for urgent formulation and implementation of second and third generation biofuels. Second generation biofuel technologies are currently at the stage of laboratory and small scale production tests. Yet, none of second generation biofuel technologies have been developed on an industrial scale, suitable for fuel market. Currently, research works on fourth generation are in progress. The fourth generation includes fuels obtained from biomass (energy plant crops and organic waste materials) or inedible oilseeds.

These include:

- bioethanol obtained through advanced processes of hydrolysis and fermentation of lignocellulose from biomass (excluding products for food purposes);
- BTL (biomass-to-liquid) synthetic biofuels constituting products of biomass processing involving gasification and deaeration, synthesis to liquid fuel components;
- fuels for self-ignition engines obtained through lignocellulose processing from biomass in Fischer and Tropsch (FT) processes;
- synthetic biodiesel from blend consisting of lignocellulose products, mixture of higher alcohols, and dimethyl ether (bio-DME);
- biodiesel as a biofuel or fuel component for self-ignition engines, obtained through hydrogen refining (hydrogenation) of waste vegetable oils and animal fats;
- biogas as a synthetically derived gas characterised by natural gas (SNG) properties, obtained through lignocellulose gasification processes and proper synthesis.

Third generation biofuels have been distinguished as a result of the need for developing more efficient methods allowing to obtain biofuels. These biofuels are obtained using methods like those employed in case of second generation biofuels, but from adequately modified raw product. Raw product used to make third generation biofuels is intended to constitute biomass that is properly modified at cultivation stage, also using biological techniques.

Prospective, fourth generation of biofuels has been separated due to the need to close carbon dioxide balance or to eliminate its impact on environment. Thus, production technologies for fourth generation biofuels should take into account the CCS processes (carbon capture and storage) for these biofuels. Raw products for making biofuels in this generation may include plants characterised by increased (even genetically) CO_2 assimilation during cultivation.

Microalgae as a potential biofuel production source

In the immediate future, microalgae may constitute one of potential plant derivative sources for biofuel production. They belong to the group of thallophytic organisms, most often autotrophic, living in aquatic environment or humid areas [Frąc, Jezierska-Tys, Tys 2009]. The idea of using microalgae as a potential engine fuel production source is not new, as it was conceived already in 1980 in Chisti's research works, and then - 1999, 2007 [Chisti 1980; 2007a; 2007b]. On average, algae biomass contains 50% of dry substance carbon, which originates from carbon dioxide necessary for algae growth [Sanchez Miron et al. 2003].

An advantage of using algae in biofuel production is that they do not compete in food products market. Oil acquired from microalgae is rich in polyunsaturated fatty acids with four and more double bonds, and such acids as eikozapentaen and dekozapentaen. It should be also emphasised that algae based biomass production is more complicated than cultivation of these plants. Unlike for oil plants, algae cultivation (production) process is definitely shorter. Generally, microalgae double their biomass within 24 hours, and oil level in the algae may exceed 80% of dry substance [Spolaore et al. 2006]. Their mass increase requires optimal production conditions including: light, carbon dioxide, water, and mineral salts. Temperature, in which algae are grown, has to fluctuate within range 20-30°C. In order to reduce biomass production costs, the process should be based on readily available sunlight. The ground in water basin for algae production requires supplying mineral components, required for algae cells growth. This primarily includes the following elements: nitrogen, phosphorus, iron and silicon. According to [Molina Grima 1990], the type of employed ground has substantial share in algae production costs, therefore sea water is commonly used, which is rich in natural phosphorus and nitrogen compounds, and other microelements.

Large-scale microalgae growing methods

An essential problem is energy consumption in production of biofuels allowing to use diversified raw products and their acquisition methods, that is so-called analysis in the whole product life chain. Energy consumption in biofuel production affects the costs involved in obtaining biofuels, as well as the volume of greenhouse gas emission, primarily CO_2.

In order to select suitable production method for algae intended for both biofuel and biomass production it is required to carry out thorough assessment of available methods. Water basins (ponds) or photobioreactors are used. Large scale algae based biomass production involves continuous cultivation, which requires artificial light supply. Most often, the pond for algae growing is built as a closed recirculation loop forming an approximately 0.3 m-deep channel lined with white plastic. In this process algae biomass is discharged after the turbine at loop end. Ponds building and their maintenance, including biomass production, is less expensive than photobioreactor costs [Chisti 2007a]. Photobioreactors allow to produce large biomass volume, are built of materials permeable for light, and allow to grow exactly the desired microalgae species [Carvalho et al. 2006].

Sunlight is the basic parameter determining increase in the share of microorganisms. In some bioreactors sunlight uses panels emitting infrared light. However, proper gas-liquid hydrodynamics affects both microorganisms growth and biomass production [Sanchez Miron et al. 1999]. The process of biomass sedimentation in photobioreactors is restricted by continuous turbulent suspension flow induced by work of mechanical pumps or aeration, which sometimes fosters its damage. It should be emphasised that algae cultivation in photobioreactors allows to obtain approximately 1/3 higher oil volume compared to algae growing in ponds [Molina Grima et al. 2003].

Biomass production cost is one of justified factors of comparative economic assessment for biofuel from algae grown in open water basins (ponds) and photobioreactors. According to the data provided in Tab. 1, estimated production cost for 1kg of biomass from algae grown in a photobioreactor is about $2.95, and in an open pool is $3.80 [Carvalho et al. 2006].

Substantial reduction in costs of biomass production using algae grown in photobioreactors, e.g. from $2.95 to $0.47, is also guaranteed by the increase in annual production due to genetic engineering processes and progress in photobioreactor technology (product with improved properties).

Table. 1. Data concerning algae-based biomass production using photobioreactor and an open basin (pond)

Parameter	Photobioreactor	Open basin
Annual biomass production [kg]	100 000	100 000
Volumetric production capacity [kg·m-3·d^{-1}]	1.535	0.117
Surface production capacity [kg·m-2·d^{-1}]	0.048[a]	0.035[b]
Biomass concentration in suspension [kg·m^{-3}]	0.072[c]	0.14
Dilution rate [d^{-1}]	4.00	0.250
Required area [m^2]	0.384	7828
Oil yield [m^3·ha^{-1}]	5681	99.4[d]
Annual consumption of CO_2 [kg]	136.9[d]	42.6[e]
System dimensions	58.7[e]	183 333
	183 333	Pond area: 978 m^2
	132 parallel tubes (units)	Width 12 m
	Tube length 80 m	Length 82 m
	Tube diameter 0.06 m	Depth 0.3 m
Number of units	6	8

Source: [Chisti 2007a]

Summary

Development of engine fuels is determined primarily by economic reasons (systematic increase in crude oil prices), natural environment protection, modern combustion engine constructional solutions, and gradual reduction of fuel consumed by automotive vehicles [Jakóbiec 2009].

Utilisation of energy from renewable sources is one of more important elements of sustainable development in economy, which brings both ecological and energy-related effects. Increase in the share of renewable energy sources contributes to the improvement in efficiency of use and saving of power raw material resources, as well as reduction in waste volumes. High potential as regards production of plant derivative biofuels shall be seen in microalgae growing. The United States and China have widest experience in this regard. Widespread, common use of these fuels instead of conventional fossil fuels will reduce carbon dioxide emissions and resolve dilemmas involved in using biofuel and bioethanol produced mainly from plants for food and animal feedstuffs.

Presented literature review proves that it is possible to produce biofuel from microalgae. According to [Frąc, Jezierska-Tys; Tys 2009], it is required to improve production economy for this biofuel due to its high costs. In order to ensure that biofuel production from microalgae is economically justified, it is required to interfere in biology of these microorganisms by means of genetic and metabolic engineering.

Independently of the presented determinants, it is necessary to continue works on introducing second generation biofuels into use, regardless of production technology being used.

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MIKROALGI JAKO POTENCJALNE ŹRÓDŁO PRODUKCJI BIOPALIW

Streszczenie. W referacie przedstawiono kierunki rozwoju rynku biopaliw w kraju na tle regulacji Unii Europejskiej jak również pierwsze doświadczenia i problemy eksploatacyjno-logistyczne. Zamieszczono obszerne informacje dotyczące potencjalnego źródła produkcji biopaliw pochodzenia roślinnego, jakim mogą być mikroalgi. Ich zaletą jest to, że nie stanowią one konkurencji na rynku produktów spożywczych.

Słowa kluczowe: biopaliwa, biodiesel, mikroalgi

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