MICROALGAL ENERGY: CHALLENGES AND PERSPECTIVES

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Abstract. To cultivate microalgae from nutrient-rich wastewater to reach pollution remediation and to utilized the produced microalgal biomass as feedstocks of renewable energy production has attracted research interest. Owing to the high growth rate of microalgae, the microalgal wastewater platform can be regarded an efficient pathway for commercial microalgal energy production. This platform is considered promising to be applied in countries that acquire intensive wastewater treatment and promoted bioenergy share.

Keywords: Microalgae; bioenergy; fuels; routes

Introduction

The world energy production and imports counted 19269 Mtoe in 2018, with oil, coal and gas being the principal energy sources. In Russia, the total energy consumption per capita was 5.3 toe in 2019, with electricity consumption rate was declined during 1990–1998, and were bound back to about 6.4 MWh per capita in 2019. The top energy sources for Russia were gas (54%), oil (20%), coal (16%), nuclear (7%), hydropower (2%), and bioenergy (1%). Overall, the energy sources for Russia are largely fossil based (>90%), while those by renewable sources were lower than 3%. The biomass resources in Russia are abundant in quantity, with crop residues, municipal sold waste, forest residue being the top contributors. Nonetheless, the bioenergy potential utilized in Russia is relatively low. The wastewater treatment coverage in Russia needs promoting and the facility being upgrading. This article summarizes an effective route of extracting energy in wastewater using microalgae platform, one of the end products being the potential sources for bioenergy available for society use.

Microalgal energy production

Microalgae platform is a promising channel for realizing bioenergy generation from waste. Microalgae are fast-growing species owing to the associated highly efficient photosynthetic efficiency to CO_2 fixation. The relatively high cell productivity, together with the high accumulation rates of intracellular lipids and carbohydrates accumulation, has made the microalgae biomass a preferred bioresource for energy production. The cost for large-scale production, pre- and post-treatments of microalgae harvesting system is commonly higher than that applicable for fossil fuels, conversely, it he nutrients of wastewater such as N and P can be removed by the microalgae cells, the expense of nutrients and that of wastewater treatment can by largely reduced. The microalgae wastewater platform for energy production is a research topic of interest. Figure 1 reveals schematically the scheme with the emphasis on the production of three kinds of biofuels, biodiesel, fermentative liquid fuels, and gaseous fuels. The pollutant removal is the bonus of using the said process in wastewater treatment that can be complying with the National Project "Ecology" (2019–2024). Under proper design and operation, an energy surplus is expected for such a waste-to-energy route in practice.

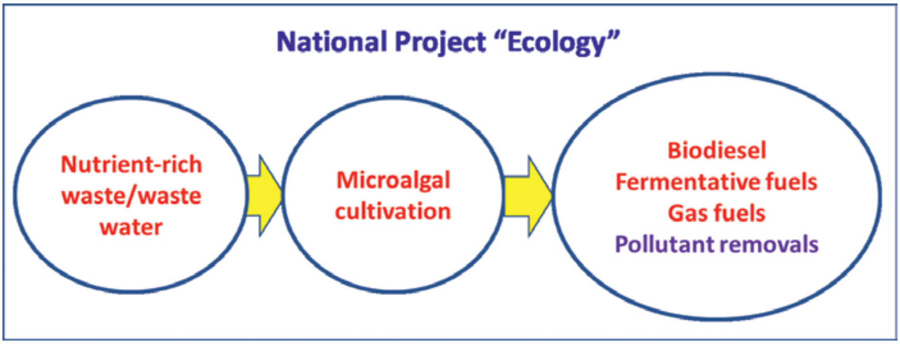

Figure 1. *Microalgal-based wastewater platform for bioenergy production*

Microalgae can grow in different types of wastewaters, depending on the physiology of the species applied. In the aspect of biofuel production, the biomass enriched in lipids and carbohydrates is commonly welcome that can be easily processed after collection since the cells commonly lack lignin in intracellular substances. One of the key process hurdles is the harvesting stage which acquires high energy input (20–30% of operational cost) for recovery of cells of reduced size from diluted suspension. Centrifugation, filtration and flocculation, flotation and sedimentation are the harvesting processes commonly adopted. For cells with high moisture content the harvested cells need immediate processing since spoilage may occur within a few hours. The use of palletization is a newly proposed route for microalgal cell harvesting in the use of pellet-forming filamentous fungi to compact the cells into pellets.

The next step is the extraction of active substances from the cell body. The release of the produced cellular compounds from microalgal cells is needed since the biological or chemical reactions can be performed only in the environment without the cell confinement. Lipid extraction processes include physical, solvent and supercritical fluid extraction. The extraction process should be rapid, specific, low loss, and minimum environmental impacts.

One of the subsequent conversions, the transesterification reaction, can generate fatty acid methyl esters (FAME), with the crude microalgal oil being converted into low molecular weight, non-toxic, biodegradable biofuel. Transesterification can be divided into conversion of lipids into glycerides and finally to FAME and glycerol. The applied catalysts including alkaline and acid, with the latter being used in commercial operations. In this process, the saponification should be avoided to reduces biofuel yield. An alternative catalyst is the solid catalysts to prevent water production and saponification. Direct transesterification is a combined extraction and transesterification one-step process to reduce the production cost.

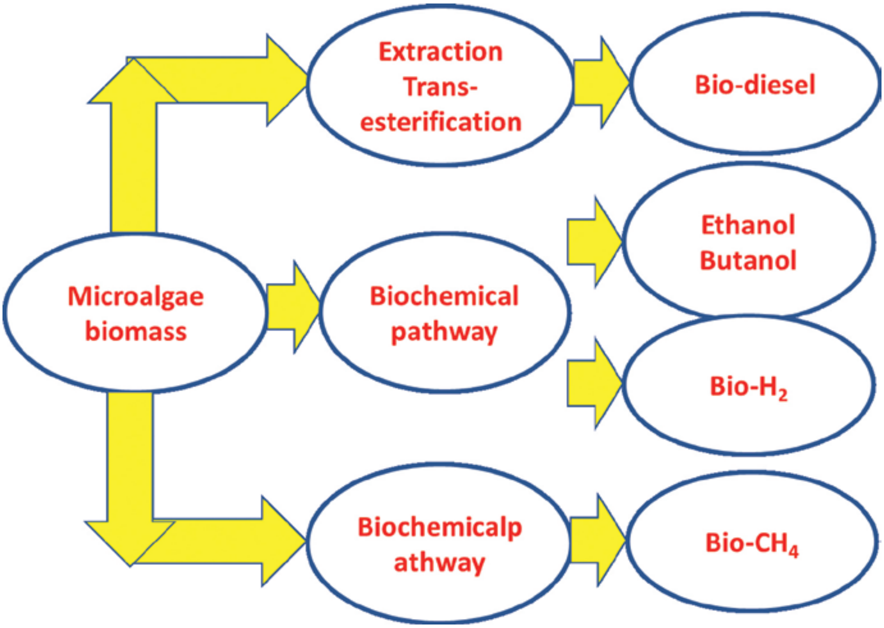

Figure 2. Microalgal energy production routes.

Another conversion route is the fermentation to produce fermentative fuels, e.g., ethanol and butanol from microalgal carbohydrates. Ethanol is a substitute for gasoline in combustion engines. Butanol has the advantages on high energy content, high blending percentage with gasoline, low vapor pressure. Microalgae have low lignin content so can be fermented to produce alcohols. The carbohydrate content of microalgae can reach 60% under nitrogen starvation, so is promising ethanol-production feedstock. Conversion of microalgal carbohydrates to bioethanol starts with pretreatment of cell mass, which extracts cellulose from biomass for saccharification stage. Feasible pretreatments include grinding, alkali/acid treatment, microwave, ultrasound and steam explosion. The pretreatment is generally expensive while some processes can generate toxic substances to inhibit further fermentation. The simultaneous saccharification and fermentation (SFF) processes were developed to ease the process operation and control. Enzymatic saccharification of microalgal carbohydrates or cellulolysis, yields glucose units for fermentation. Enzymatic saccharification is slow but acquires reduced energy demand and generates minimal quantity of inhibitors. Compared with bioethanol, the production of butanol from microalgal carbohydrates are in infant development stage. The ABE fermentation is commonly applied for biobutanol production while the pH reduction in fermentation presents one of the major constraints for its commercial production.

The biohydrogen and biomethane are gaseous fermentative fuels from microalgal carbohydrates. Direct production of biohydrogen by microalgae is generally at low rate. The alternative route is dark fermentatively to produce biohydrogen from microalgal carbohydrates. The dark fermentation pathway is part of the anaerobic digestion process while the inhibition of methane generation can lead to hydrogen accumulation. Via ABE fermentation pathway the alcohols and biohydrogen can be simultaneously generated. However, commercial production of biohydrogen are still not practiced since the conversion rate is low and the purity is not high. The combined dark and photo fermentation production route is a promising way to maximize utilization rate of substrate to biohydrogen. Another potential extension is to combine dark fermentation and methanogenic process to achieve biomethane production. Biomethane is the terminal gaseous fuel via anaerobic digestion pathway, which is the currently mostly adopted renewable energy source, widely applied in European countries. Microalgal biomass is with a low C/N ratio so the co-digestion with other substrates with high C/N ratio is commonly the option to maximize the yield of biomethane. Up to the present stage the biomethane is also the only bioenergy that has a chance to compensate its own operating costs by its market sale.

Commercial scale microalgae cultivation acquires huge quantity of water, which can compete with drinking water sources if fresh microalgae is to be cultivated. Also, the nutrients needed for microalgae cultivation including nitrogen and phosphate would be expensive and carbon-intensive if external dosage of fertilizer is needed. Strong wastewaters including sewage, landfill leachate, and other agricultural and industrial wastewater are promising media which has excess water and nutrients, with nutrients being considered as the substrates for microalgal growth. If the wastewater can be handled by microalgae to achieve nutrient removals and excess biomass production, the latter can be an adequate feedstock for bioenergy production, as described in this section. In doing so, a microalgae wastewater platform can be realized, which is assumed to be a promising option to cope with current development goals of Russia.