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# Use of Biomass for Producing Liquid Fuel: Current State and Innovations

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**Abstract**—Current matters relating to utilization of biomass for producing energy are discussed, including the most developed technologies of biopower engineering and innovative developments, as well as the possibilities of using nonfood raw materials as second-generation biofuel. It is shown that microalgae can be considered as prospective sources of different kinds of renewable biofuel, such as methane, biohydrogen, bioethanol, biobutanol, pyrolysis biofuel, biodiesel, and renewable diesel fuel, and can serve as an alternative to the traditional cultures used for power-generating purposes.

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Accelerated development of the biopower engineering has become in recent years a global worldwide tendency. More than a hundred leading companies from 17 countries around the world are engaged in studies, development of technologies, designing of facilities for the biofuel industry, and production of renewable fuel; 48 countries around the world have legislatively fixed and actively developed production and use of biofuel. Both economic and environmental problems can be solved through the use of such fuel, including the following ones:

(i) replacement of fossil resources;

(ii) diversification of energy sources to ensure energy security of importing countries;

(iii) additional production of competitive exported products in the agricultural sector of economy; and

(iv) reduction of the amount of greenhouse gases emitted into the atmosphere.

A tendency toward increasing the consumption of biofuel is observed in the majority of developed countries. According to different estimates, the rates of increase in the production of different kinds of liquid biofuels around the world range from 20 to 40% a year. The European Union's directive issued on May 14, 2003, demanded that the fraction of biofuel in the total amount of liquid fuels consumed in European countries should increase to 5.75% by 2010, but in March 2009, a new directive was adopted, according to which European countries were requested to increase the fraction of renewable fuels to 10%. The world's biofuel industry is transferring to the stage of a successful and rapidly growing branch that attracts increasingly growing attention of so-called traditional fuel players, investors, and states. Thus, the amount of investments in this industry, e.g., in the United States has reached $150 billion for the last decade [1].

## A BRIEF REVIEW OF TECHNOLOGIES FOR PRODUCING LIQUID FUEL FROM BIOMASS

Until recently, production of liquid fuel around the world has been limited mainly to production of bioethanol and biodiesel fuel, for which grain and oil cultures were used as raw material. This gave rise to a contradictory attitude to biopower engineering as a large-scale consumer of food resources and stimulated development of technologies for obtaining biofuel from nonfood raw material, primarily from the lignocellulose contained in waste wood, agricultural wastes, etc.[1] As a result, construction of more than 70 plants for producing biofuel from nonfood raw materials was commenced around the world.

At present, the term "biofuel" is understood to mean fuel produced from any kind of biomass (organic substances of vegetable and animal origins) that can be converted into thermal energy. The existing classifications of biofuel are based on the type of used raw material. Thus, first-generation biofuel encompasses biofuel produced from food raw materials, and second-generation biofuel includes biofuel obtained from various wastes (like wastes from food, wood and woodworking industries, and agriculture). In our opinion, it is advisable to introduce the term *third-generation biofuel* produced from the biomass of microalgae,

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[1] However, according to the data of the U.N.O.'s Food and Agriculture Organization, the increase in the price for food was largely due to other factors: a low level of crops in countries exporting agricultural products, growing demand for food in rapidly developing countries of Southeast Asia, and a growth of prices for energy carriers. An analysis of the ratio of prices for petroleum in the past 2 years shows that there is no relation between the production of biofuel and the growth of prices for food products. In 2008–2009, the prices for grain dropped in step with the prices for petroleum despite the rapidly increasing production of biofuel around the world [2].

because microalgae are cultivated specially for power-generating purposes and are not a traditional food raw material. At the same time, the biomass of microalgae does not fall under the category of wastes, i.e., the category of second-generation biofuel. In addition, biomass of microalgae contains many valuable accompanying substances, the cost of which is frequently higher than the target power-generating product, due to which the produced biofuel becomes cheaper.

A distinction should be made between the classification given above and classification with regard to technologies used to produce biofuel. According to the commonly adopted terminology, the technology of obtaining biodiesel fuel from triacylglycerides (TAGs) is called *first-generation* technology, and the technology for producing renewable diesel fuel is called *second-generation* technology, whereas the sources of raw material in both the cases can be the same.

Table 1 lists the kinds of the liquid biofuels and methods for obtaining them from biomass using the modern technologies. A more detailed analysis and classification of methods for producing energy from biomass, as well as technologies for processing it, are given in [3–5].

The presented list of the technologies and kinds of biofuels does not pretend to be absolutely exhaustive, because information about development of new technologies and revealing of new kinds of microorganisms producing biofuel (in particular, ethanol), emerges every day. With new technologies put in use, the same biomass can serve as a source of different kinds of fuel. For example, biomass containing oil or fat is used to produce biodiesel fuel—a liquid biofuel obtained by subjecting triacylglycerides to transesterification [6, 7]. However, in its chemical composition, biodiesel fuel has nothing in common with mineral diesel fuel produced from petroleum. At present, much attention is paid to obtaining *renewable diesel fuel* from any biomass, which is close in its composition to mineral diesel fuel.[2]

Renewable diesel fuel has the following advantages over biodiesel fuel:

(i) It can be used at low temperatures.

(ii) Propane, a substance that has obvious advantages over glycerin, is obtained as an accompanying product.

(iii) It has a higher heating value and cetane ratio.

(iv) Its production is characterized by smaller capital and operating costs.

As a result, the tendency toward making a shift for using the technology of producing renewable diesel fuel is now becoming tangible. Thus, several companies in different countries have announced construction of facilities for producing it on the basis of hydroprocessing [8]:

—In Finland, the Neste Oil Corp.'s factory for producing the renewable diesel fuel from vegetable oil and animal fat was opened in May 2007, and there are plans to construct two more factories.

—Italy's ENi announced the launching of similar production by subjecting vegetable fat to hydro treatment with bringing the yield to 360000 m$^3$ per annum by 2009.

—Brazil's Petrobrass is now producing the renewable diesel fuel using a patented technology of hydro cracking.

—In April 2007, Conoco-Philips (Ireland), launched production of the renewable diesel fuel from rape seed and—in partnership with Tyson Foods—from waste animal oils; the volume of production was supposed to reach 650000 m$^3$ per annum in 2009.

Biomass can be subjected to hydroprocessing in parallel with producing diesel fuel from petroleum; hence, the infrastructure of petroleum refineries can be used (coprocessing).

The technologies for obtaining biodiesel fuel by subjecting TAGs to transesterification and for obtaining the renewable diesel fuel using the hydroprocessing method require that initial raw material should have a high content of lipids. Unlike these, the biomass-to-liquid (BTL) technology can use any biomass. At the first stage of this process, raw material is subjected to gasification, the main product of which is a mixture of carbon monoxide and hydrogen (synthesis gas). Wood chips, sawdust, briquetted straw and remainders of cereals, wastes from power production facilities, and specially grown power-generating biomass (wood, silver grass, and algae) can all be used as organic raw material for the BTL technology. Synthesis gas can be used as initial material for producing a wide range of organic compounds, including engine fuel. Synthesis gas can be transported and stored using the existing fuel infrastructure, and no changes need to be done in the design of engines in shifting motor vehicles and tractors for firing the synthetic fuel obtained from synthesis gas. Synthetic fuel can be used either alone or in a mixture with diesel fuel. The factory constructed by Choren in Freiburg (Germany) in 2008 with the design capacity equal to 18 million liters of liquid fuel a year is the world's first project on using the BTL technology. This fuel will be produced under the name Sun Diesel. Choren also has plans to construct a similar factory in Schwedt (Eastern Germany) at the end of 2010 with a capacity of 200000 t of BTL fuel (around 1 million t of wood chips will have to be processed to obtain this yield) [9]. The capital outlays for producing BTL fuel are a factor of 7 higher than those for producing fuel from petroleum and a factor of 4 higher than those for producing ethanol [10].

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[2] The terms "green diesel" and "sun diesel" are also used in the literature.

**Table 1.** Kinds of liquid fuels and methods for obtaining them

| Name | Production methods | Raw material |
|---|---|---|
| Biodiesel fuel | Subjecting triacylglycerides (TAGs) to transesterification | Vegetable oils and animal fats |
| Renewable biodiesel | 1. Subjecting TAGs to hydroprocessing<br>2. Subjecting biomass or products of its pyrolysis to gasification followed by catalytic conversion of biogas using different methods, including Fisher—Tropsh's technology and BTL | Biomass or products of its pyrolysis |
| First-generation bioethanol from food raw material | Subjecting carbohydrate-containing raw material to alcoholic fermentation by yeast | Sugar cane, wheat, corn, potato, etc. |
| First-generation biobutanol from food raw material | Subjecting dissolved sugars to acetone-butyl fermentation by anaerobic clostridia | " |
| Second-generation bioethanol from lignocellulose raw material | 1. Alcoholic fermentation:<br>(a) pretreatment of lignocellulose raw material to obtain soluble sugars;<br>(b) subjecting dissolved sugars to fermentation by yeast;<br>(c) drying the obtained ethanol.<br>2. Subjecting biomass to gasification followed by converting the obtained synthesis gas into ethanol.<br>3. Catalytic synthesis of ethanol | Lignocellulose biomass |
| Second-generation biobutanol from lignocellulose raw material | 1. Pretreatment of lignocellulose raw material to obtain soluble sugars.<br>2. Subjecting dissolved sugars to acetone-butyl fermentation by anaerobic clostridia. | " |
| Liquid pyrolysis fuel (biopetroleum) | Fast pyrolysis | " |
| Third-generation biofuel from microalgae biosynthesis products | Biosynthesis of:<br>(a) ethanol and hydrogen by algae;<br>(b) carbohydrates (followed by subjecting them to alcoholic or acetone-butyl fermentation to obtain bioethanol and biobutanol);<br>(c) hydrocarbons (followed by subjecting them to hydrocracking to obtain kerosene, gasoline, diesel fuel, fuel oil, and other products)<br>(d) TAGs (to obtain aviation fuel by subjecting them to hydroprocessing and biodiesel fuel by subjecting them to transesterification | Biomass of algae |

* Hydroprocessing includes hydrocracking, hydrogenation, and hydropurification.

**Table 2.** Comparative assessment of sources of raw material for producing biodiesel*

| Culture | Oil crop, l/ha | Area required for producing oil, Mha*[2] |
|---|---|---|
| Corn | 172 | 1540 |
| Soy-bean | 446 | 594 |
| Canola | 1190 | 223 |
| Nettle spurge | 1892 | 140 |
| Coconut | 2689 | 99 |
| Palm oil | 5950 | 45 |
| Microalgae (30%)*[3] | 58700 | 4.5 |
| Microalgae (70%)*[4] | 136900 | 2 |

* The data are obtained in experiments for growing microalgae on an area of 5681 $m^2$ in New Zealand.

*[2] To replace 50% of the entire transport fuel in the United States.

*[3] 30% of oil (from biomass by solid mass).

*[4] 70% of oil (from biomass by solid mass).

## BIOMASS OF MICROALGAE AS A SOURCE OF ENERGY

At present, the biopower potential of algae attracts great attention of biofuel producers, who invest considerable sums of money in research programs. We are also witnessing growing rates of scientific studies and experimental-industrial developments in the field of algae-based biofuel brought to the stage of commercialization.[3] It should be noted that numerous private companies participate along with governmental organizations of many countries in works on developing the main stages of the technological process through which microalgae fuel is obtained. Such interest in algae stems from the fact that their biomass has many attractive properties and meets the majority of requirements imposed on vegetable raw materials for power-generating purposes. Below, these advantages are considered.

—Withdrawal of the cultivated biomass of microalgae for power-generating purposes does not upset the natural conservation of organic substances in the biosphere [11]; in addition, plantations of microalgae serve as an efficient short-term sink for man-made $CO_2$, converting it into high-density energy.

—Algae are photoautotrophs; that is, they need sunlight, $CO_2$, and water with a small quantity of mineral salts for their growth.

—The quantity of biomass and oil yielded from microalgae is several tens of times higher than that from terrestrial plants, including oil-bearing plants:

| Algae | Content of lipids, % |
|---|---|
| *Scenedesmus dimorphus* | 16–40 |
| *Prymnesium parvum* | 22–38 |
| *Euglena gracilis* | 14–20 |
| *Chlorella vulgaris* | 14–22 |
| *Dunaliella salina* | 16–44 |
| *Haematococcus pluvialis* | 25–45 |
| *Tetraselmis suecica* | 20–30 |
| *Isochrisis galbana* | 22–38 |
| *Nannochloropsis* sp. | 33–38 |
| *Stichococcus* sp. | 40–59 |
| *Botryococcus braunii* | Up to 80 |

It is important to note that the areas required for growing these algae are much—by a factor of 50 to 100—smaller than those required for cultivating, e.g., rape seed (Table 2) [12, 13]. In addition, no arable lands are required for growing algae; their plantations can be placed on the surface of water basins or on soils unsuitable for agriculture (saline, desert, etc.).

—Algae require much less water than the traditional cereals; algae can be grown in salt water and in sewage water, which makes it possible to use smaller amounts of pure water.

—Microalgae do not belong to the category of traditional raw food materials.

—One of the possible ways in which the cost of biofuel obtained from microalgae can be reduced consists of using them simultaneously to obtain valuable accompanying products for the chemical, pharmaceutical, medicine, food, and fodder industries (beta-carotene, astaxanthine, phycocyanine, chlorophyll, glycerin, etc.) and using wastes from other production processes for cultivating them.

—With the technologies now available around the world, it becomes possible to cultivate the biomass of algae on a large scale all year round, not only under the conditions of tropical and subtropical climate, but also in zones with moderate climate, even at negative temperatures of outdoor air in winter [14].

The research studies and engineering developments aimed at *producing microalgae biofuel* are focused at a *culture of microalgae* that should feature the ability to rapidly grow, and synthesize and accumulate considerable quantities of lipids in the form of triacylglycerides and liquid hydrocarbons. In view of this, microalgae satisfying these requirements are being searched for in natural populations. It has been found that representatives of green and diatom microalgae are the most promising producers of TAGs, the highest content of which (40–60%) has

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[3] According to commonly adopted gradation, open cultivation of microalgae on an area larger than 10 $m^2$ corresponds to a stage of laboratory studies, that on an area larger than 50 $m^2$ is a pilot stage, cultivation on an area larger than 200 $m^2$ is a demonstration stage, and that on an area larger than 1000 $m^2$ is a commercial stage.

been found in diatom microalgae. At present, only two cultures of microalgae producing liquid hydrocarbons are known: *Bortyococcus braunii* and *Pseudochoricystis ellipsoidea* (the latter strain has recently been separated by Japanese scientists) [15]. According to a decision made at the US Solar Energy Research Institute/National Renewable Energy Laboratory within the framework of the Aquatic Species Program [16], the first collection of microalgae from fresh and salt water basins has been gathered, which is a valuable genetic resource.[4]

Apart from active search for natural microalgae producing lipids, work is being carried out—by means of mutagenesis and using gene engineering methods—on creating new strains of microalgae featuring high output of biomass and target product, which is one of the main requirements of commercial production.

Achieving more efficient photosynthesis and optimizing the biosynthesis of lipids are the tasks pursued by many research programs. As is known, algae can efficiently use 10% of incoming sunlight, whereas the remaining 90% is spent useless and can even inflict damage to the photosynthesis system and produce the effect of photoinhibition. One possible way of using sunlight more efficiently consists of reducing the size of a light collecting antenna by mutation or by applying gene engineering methods. This will make it possible to organize such conditions under which the photosynthesis system will absorb only the quantity of sunlight it can use. As a consequence, smaller losses will be achieved, the hazard of photo-oxidation occurring in the photosynthesis reaction center will be reduced, and a higher additional crop from microalgae culture will be obtained. In [17], the possibility to achieve high effectiveness and high level of saturation with sunlight for algae cultures was demonstrated.

To avoid difficulties in cultivating microalgae on a commercial scale due to inadequate illuminance, researchers took the path of creating heterotrophic strains of algae from obligate photoautotrophs. After a gene responsible for transportation of glucose had been entered into *Phaeodactylym tricornitum* microalgae, this culture became able to utilize exogenous organic carbon and grow independently of light. This was the first successful trophic conversion of an obligate photoautotroph carried out using metabolic engineering, which has shown that the cell feeding method can be changed fundamentally by introducing one gene [18]. A method has been patented according to which diesel fuel is obtained using the *Chlorella kessleri* strain of heterotrophic chlorella that allows a high output to be obtained equal to 108 g/l of biomass and 52% of oil per dry mass [19]. Specialists of Solazyme (the United States) also work on obtaining genetically modified strains of algae with a heterotrophic type of feeding with the purpose of reducing the cost of producing biodiesel fuel from algae through reducing the infrastructure of production facilities and simplifying the work on harvesting the biomass of algae and separating oil from it. By cultivating such microalgae it becomes possible to remove problems of ensuring a certain level of illuminance and use the well-developed infrastructure of the microbiological industry; as it regards the necessary carbohydrates, sugars from cellulose can serve as sources of these substances [20].

Considerable progress has been achieved in making insight in the process through which lipids are accumulated in microalgae. It has been found that, if the nutrition medium in which diatomic algae are cultivated contains insufficient quantity of silicon, which is the main component of the intercell wall of diatom algae, this shortage may induce synthesis of lipids. In green algae, lipids are synthesized and accumulate under the conditions of nitrogen starvation. The mechanism that triggers accumulation of lipids has not been fully understood. Supposedly, insufficient nutrition may affect such specific biochemical paths as accumulation of lipids accompanied by an increase in the quantity of spare lipids (triacylglycerides) with respect to polar membrane lipids. As it regards diatom algae, shortage of silicon in the nutrition medium is a factor that increases the expression of at least one gene participating in the synthesis of lipids, namely, acetyl-CoA-carboxylase. The gene coding the production of this ferment has been isolated and cloned. Isolation of these genes helped to develop gene transfer systems in diatom algae. It was shown that superexpression of this ferment is possible, which gives hopes for increasing the activity of acetyl-CoA-carboxylase in a cell and obtaining a higher content of oil in algae [16].

Two methods of cultivation are used for realizing the biosynthesis abilities of natural and modified strains of autotrophic microalgae: in photobioreactors (PBRs) and in open cultivators. The use of PBRs (the closed method) makes it possible to maintain controlled conditions in them and obtain a high yield of product. However, this method of producing microalgae involves high costs. The use of open ponds is much less expensive; however, these ponds are very susceptible to contamination, and only three kinds of algae, namely, chlorella, spirulina, and dunaliella were found to be able to be cultivated on a large scale under such conditions. Smaller cost of microalgae production is achieved by using low-grade rejected heat and gaseous discharges from thermal power stations, wastes from cattle-breeding complexes, and so on. The existing technologies for producing fuel from microalgae are schematically shown in Fig. 2.

All advantages of PBRs and open cultivators can be combined in hybrid systems. Thus, in 1997–2001, large-scale cultivation of *Haematococcus pluvialis*

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[4] This collection is stored at the Hawaiian University and is accessible for researchers.

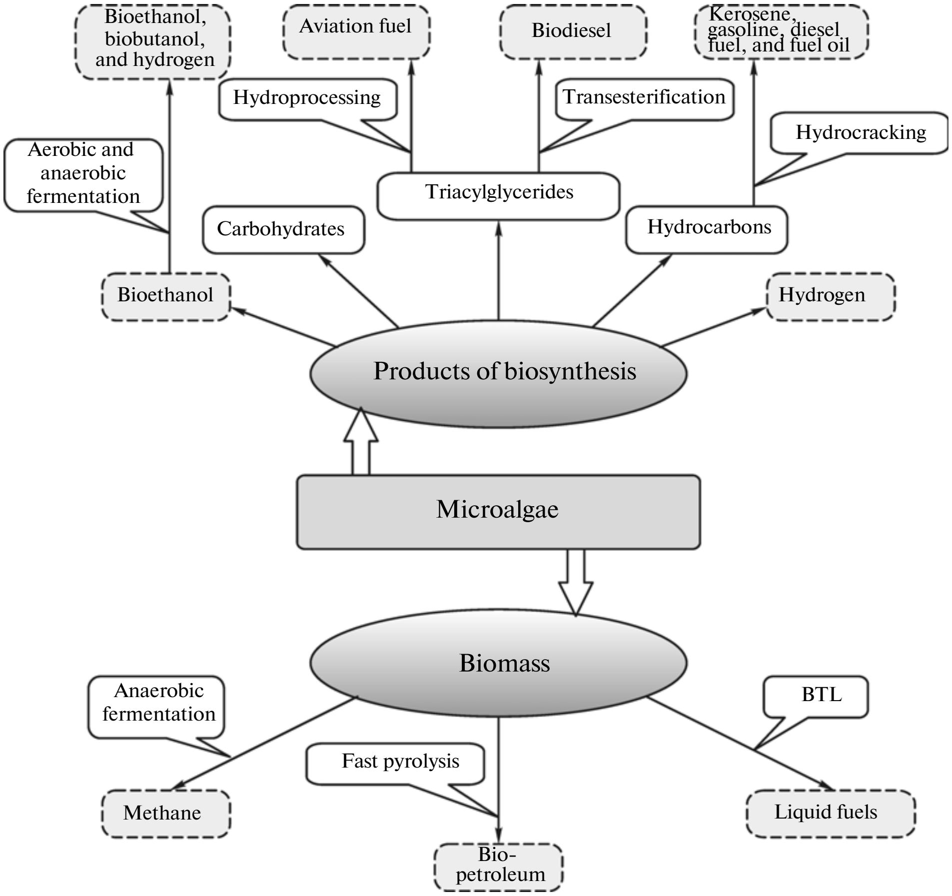

**Fig. 1.** Modern lines of using microalgae for power engineering purposes.

green microalgae was successfully implemented in Hawaii using a hybrid system [13]. The use of a PBR makes it possible to organize stable cultivation of algae that cannot grow in open cultivators and provide a continuous supply of high-quality inoculum to open ponds. The high rate with which algae grow in open ponds allows the volume of biomass to be increased within a short period of time (1 or 2 days) and helps avoid it becoming infected by extraneous microflora, and the limited quantity of nutrition substances that takes place under such conditions is a factor that stimulates biosynthesis of oil and astaxanthine pigment. The system for continuous cultivation of microalgae proposed in this project consisted of closed tubular photocultivators and open ponds with the total area equal to 2 ha. The average quantity of energy generated from the biomass of *H. pluvialis* made up 763 GJ/(ha year) and that by oil, 422 GJ/(ha year). The maximal yields made up 1836 and 1014 GJ/(ha year). These values are considerably higher than those for terrestrial vegetation, the major part of which gives an output from 50 to 400 GJ/(ha year). The economic assessments presented in [13] showed that the cost of biodiesel fuel produced from microalgae in this project was close to the current world prices for mineral diesel fuel.

Development of efficient *methods for extracting and transforming algae oil* is an important aspect of using microalgae for power-generating purposes. The need to subject biomass to filtration and chemical extraction of oil from it can be avoided using the method proposed by specialists of Origin Oil (the United States), the idea of which consists of treating algae suspension in an alternating electromagnetic field with varying the pH value by adding $CO_2$. Such treatment results in that the cell wall of algae is destructed and oil floats up [21]. The method developed on the basis of acid catalysis [22] allows the processes of extracting lipids from microalgae and obtaining biodiesel fuel to be combined in a single stage. The culture can be kept alive during the extraction of lipids from it by using mesoporous nanoparticles that extract oils from live cells of algae; further extraction of oil is performed using Catilin, a specially developed and patented catalyst [23]. Crude glycerine, which is a byproduct in the process of obtaining biodiesel fuel, can be converted into bioethanol by subjecting it to anaerobic fermentation by means of colibacillus (*Escherichia coli*) [24].

Earlier, algae biofuel projects were focused at obtaining biodiesel fuel, but at present, owing to innovative technologies, producers are becoming inter-

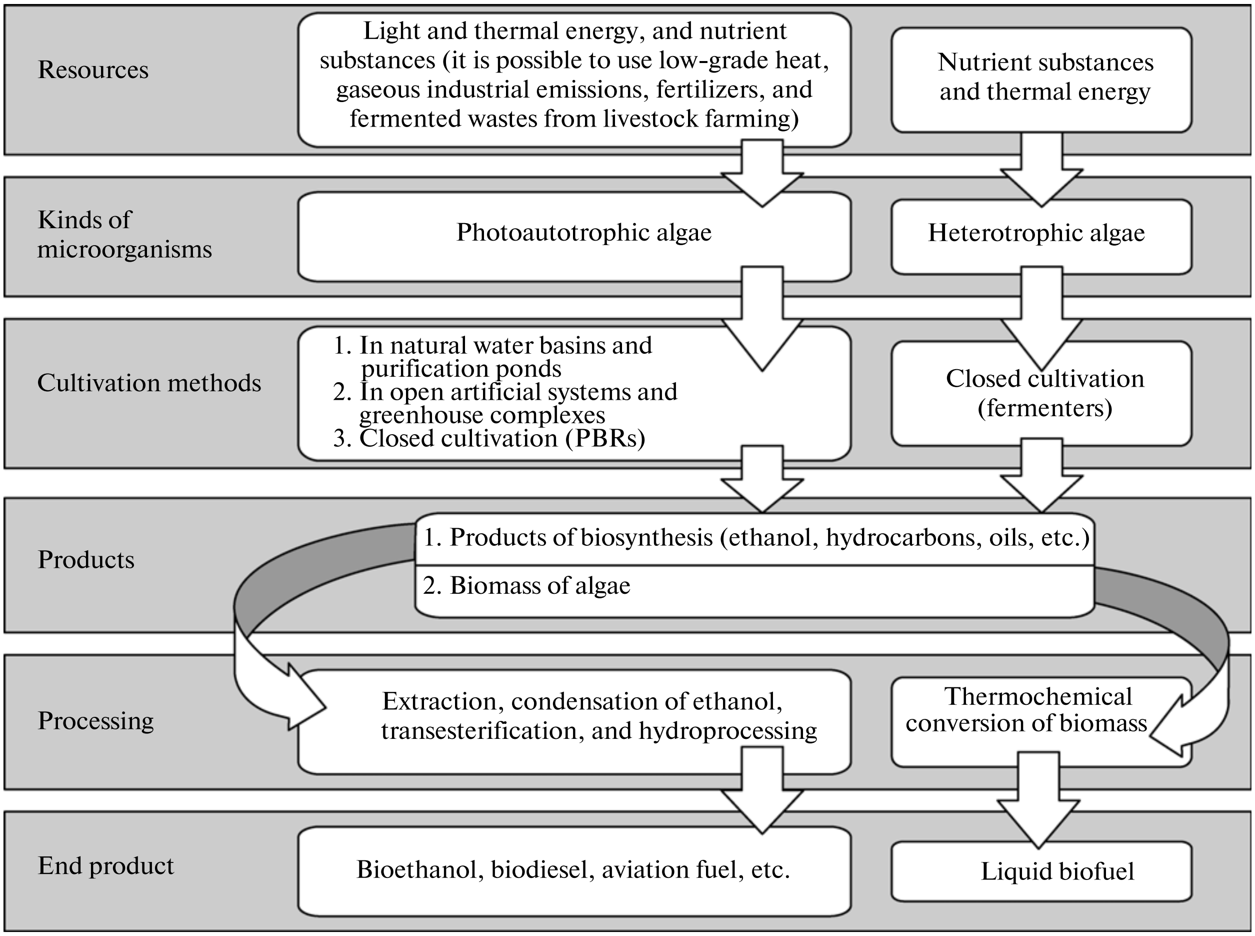

**Fig. 2.** Schematic flowchart of obtaining liquid fuel from microalgae.

ested in the possibility of obtaining other kinds of fuel from algae that are close in composition to fuel products obtained by petroleum distillation, e.g., aviation fuel, which is obtained by subjecting algae oil to hydroprocessing. Chevron and other private companies have invested $75 million for cultivating microalgae in California for these purposes (the Solazyme Co. is the contractor of this project). Sapphire Energy received $100 million from Caskad Investment and Rockfeller Foundation for development of the demonstration project of a system for obtaining biopetroleum from algae and producing gasoline from it [25].

The project developed by Algenol Biofuels (Mexico) for producing ethanol synthesized by genetically modified cyanobacteria is also of great interest. This company has plans to construct jointly with Dow Chemical a demonstration plant with an area of 97000 m$^2$ for a design output of 380000 l of ethanol a year. Supposedly, the net cost of 1 l of ethanol will be reduced to 30 cents. It is expected that the content of energy in the end product will be a factor of 5.5 higher than the total expenditure of energy for production. In this case, the ethanol obtained from algae will be competitive with respect to ethanol produced from cellulose [26]. According to schedules, the production should be commenced in 2010; the volume of production should reach 3.78 billion l in 2012 [27].

Recent years have seen an active growth of investments in algae projects: in 2008, the sum invested in such projects in the United States alone totaled more than $300 million. Leading companies in the United States have plans to bring the production of algae biofuel to commercial levels within the next 2–3 years: Solazyme, 3.78 million l/year by 2012–2013, and PetroAlgae, 3.78 million l/year by 2011. At the same time, European Algae Biomass Association is somewhat skeptical about the American projects, pointing out that the production of algae fuel can be brought to a commercial level no earlier than 10–15 years.

## STATE OF RUSSIAN STUDIES AND DEVELOPMENTS IN THE FIELD OF USING MICROALGAE FOR POWER-GENERATING PURPOSES

Unfortunately, for Russia, even the statement of the European Algae Biomass Association sounds too optimistic, because in Russia there are no national programs for development of algae biopower engineering. Russian collections of microorganisms do not contain strains that hold promise for production of liquid biofuels. There is also a problem of training skilled specialists: none of the biological departments in Russian universities suggests a program aimed at training or refresher training of specialists in biopower engineering, in particular, algology. Nonetheless, the past recent years have witnessed that practical interest is arising in algae as a potential source of biofuel, which can be seen from the fact that international conferences under the aegis of the National Biofuel Association, Federal Center of Biopower, Russian Agricultural Academy, etc., are held in Russia. In particular, specialists of the laboratory of biotechnology for the petroleum and gas industries at the Gubkin Russian State University of Petroleum and Gas announced works on developing technologies for obtaining biofuel from microalgae. Works are also carried out on obtaining biohydrogen using microorganisms (the Institute for Fundamental Problems of Biology, Russian Academy of Sciences).

For the past two decades, specialists of the Moscow State University's Research Laboratory of Renewable Energy Sources have been conducting research works for large-scale cultivation of biomass of microalgae in open planar photocultivators both for power engineering purposes and for integrated use as fodder and food additions. Due to a widely variable morphology of microalgae strains, especially when such algae are cultivated using the open method, problems connected with identifying them arise, which generates the need to systematize microalgae. The authors of this paper have shown in their studies that the geometrical parameters characterizing the trichome spiral of *arthrospire/spiruline* are not a valid taxonometric criterion in the species differentiation of arthrospires.

The authors of this paper see their main objective in broadening the search in natural conditions for strains adapted for regions of their supposed cultivation. In this connection, we conduct a search for cultures that are representatives of the *Botryococcus* genus in water basins in the Moscow and Tver regions. The *Botryococcus braunii* single-cell colonial algae is a representative of this genus, which, owing to its ability to produce considerable quantities of hydrocarbons (up to 86% of dry biomass) is regarded as a potential source of renewable fuel [28]. Historically, interest in this alga arose due to its participation in geochemical processes: paleobotanical studies show that *B. braunii* is one of the main sources from which hydrocarbons appeared in various deposits rich in petroleum, starting from the Ordovician period until nowadays [29]. Analysis of petroleum from Sumatra deposits has shown that this petroleum contains botryococcane (a derivative of botryococcene, substance produced by *B. braunii*) in an amount of 0.9–1.4%, which is the highest level for the biological marker of petroleum. Balkhashite, a combustible fossil substance discovered by M.D. Zalesskii more than a century ago, is also produced by lipids of *B. braunii* [30]. In addition, Zalesskii found remainders of this alga in sapropel of Lake Vel'e in the Valdai Upland [31]. The authors of this paper organized expeditions on surveying Valdai lakes and studied if any colonies of *B. braunii* were available in them. Samples of *botryococcus* were isolated to determine more exactly their systematic position, analyze the content of hydrocarbons in them, and estimate the prospects of using them as raw material for obtaining biofuel. An analysis of data available in the literature, a search of cultures in Russian and foreign collections, as well as own works of the authors on isolating cultures from natural sources were used as the basis for constructing a database and setting up a collection of lipid-producing microalgae at the laboratory of renewable sources of energy in the Geographic Department of Moscow State University [4, 32–34].

## CONCLUSIONS

(1) Use of biomass for producing liquid biofuel is becoming a rapidly developing industry that requires innovations for accelerated commercialization. The amount of money that has been invested, the technologies that have been developed, and the production facilities that have been constructed are such that the so-called return point has been passed. Production of biofuel has become a national idea in the United States and European Union.

(2) By natural yield of bioproduct and content of energy, microalgae are several tens of times more efficient than traditional biomass as raw material for producing liquid biofuel. Many scientific-technological centers around the world are constantly working on improving technologies for producing and reprocessing the biomass of microalgae, thus creating a basis for making a shift in the next few years from research and experimental design works to commercial production of liquid fuel from microalgae.

(3) In Russia, interest in this sector of biopower engineering is only awakening. In view of the background of scientific and research works that is available in Russia, an important avenue of works is seen in conducting further studies and developments on obtaining commercial strains of lipid-producing microalgae, including those tolerant to low cultivation temperatures, as well as studies on using heterotrophic strains of microalgae taking into account the great experience that has been gained in the microbiological industry of Russia.

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