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Foresight of Microalgae Usage for the Production of Third-Generation Biofuel

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Abstract

Objectives: To study the capabilities and evaluate the potential of microalgae usage for the production of third-generation biofuel. **Methods:** During the research comparative analysis methods and studying and forecasting available statistics methods were used that are related to the production and marketing of algal biofuel worldwide. **Findings:** It was established that microalgae, on the potential energy yield per unit area, can surpass by far a number of oil-bearing plants. Yet, the production of third-generation fuel from microalgae biomasses currently wields a low economic efficiency, due to the high cost of its cultivation, and is substantially not developed despite the technical feasibility. It is shown that for the assessment of the current status of the production of biofuels from microalgae it is wise to use a promising fuel management readiness level methodology. **Applications/Improvement:** The possibility to overcome the existing barriers to economically efficient mass production of biofuels based on microalgae was established, and for that it is necessary to engage in reducing its cost.

Keywords: Aviation Industry, Biofuel of Third Generation, Economic Profitability, Fuel Readiness Level, Innovative Development, Microalgae, Technological Roadmap

1. Introduction

Biofuels is one of the potential options for reducing fossil fuel dependence. Some experts predict a significant increase in global demand for biofuel in the next decade. As for today, biofuel has a special place in the structure of renewable energy sources. It is one of the few types of alternative fuel in the transport sector and it is regarded as an important resource in the choice of energy sources and energy security, agriculture and rural development, as well as to mitigate climate change by reducing emissions of greenhouse gases.[1]

A biofuel which can be produced without significantly increasing the use of agricultural land, reduction of the tropical rainforest area and consumption of large amounts of fresh water is very attractive in the near future. Thus, algae may become an effective renewable biomass for biofuel production in the near future, especially microscopic algae - microalgae (single-cell algae), capable of growing even in salty and polluted water. Depending on the variety, their size may range from a few micrometers to several hundred micrometers. Unlike higher plants, microalgae have no roots, stems and leaves. They do not bloom and don't form seeds. Microalgae, carrying out the photosynthesis process, play an important role in the provision of life on Earth. They produce about half of the atmospheric oxygen and during their growth process they absorb carbon dioxide, thereby reducing the greenhouse effect. Microalgae have a very broad biodiversity, yet, in the meantime they are a practically unused resource. So, it is estimated that there are about 200,000-800,000 species of microalgae, from which about 50,000 species are officially known and described. Algae began to be cultivated in large quantities during the 50s of the last century for the needs of the pharmaceutical industry. Only relatively recently have they become seriously considered as a potentially cost-effective renewable energy.

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2. Concept Headings

Microalgae are usually grown in open ponds or in artificial closed systems known as photo bioreactors. Larger species of algae, known as macroalgae, can be directly grown in the sea or in special fermentation vessels. On the 2010-held financial summit of organizations which are engaged in the production of algae biomass, representatives of a well-known consulting industry stated that 98% of the objects intended for the cultivation of algae are open ponds, while 98% of all studies are conducted in photo bioreactors. Each of the methods of algae cultivation has its pros and cons. Cultivation of algae in open ponds and shallow pools are usually cheaper compared to other methods, and easier on the technical side, but are vulnerable to weather conditions, external pollution, invasion of less desirable strains and consume more water. Such type of algae cultivation can be carried out in natural and artificial systems. The most wide-spread artificial systems consist of tens, or in some cases hundreds of "raceway" type cultivators, in which the microalgae suspension circulates constantly thanks to the action of paddle mixers, also known as airlift pumps.[2] Significantly more rarely microalgae are cultivated in natural water ponds (lagoons and lakes) without the usage of forced mixing.[3] The process of cultivation is controlled easier in closed systems, algae grow faster, yet these growing methods are more expensive and their scalability can be rather problematic. The approximate price of photobioreactors installation for microalgae cultivation ranges from $ 500 thousand up to $ 1 million per hectare.[4] However, mass production of photobioreactors currently exists. So, the Bioking Company began mass production of patented photobioreactors, suitable for immediate use and cultivation of fast-growing algae with high oil content. It's rather interesting that the first, in many ways, experimental mass cultivation of microalgae attempt was undertaken in 1950, namely in photobioreactors: two small photobioreactor were installed in the US on the roof of a building at the Massachusetts Institute of Technology.

Cultivation of algae in photo bioreactors involves high-operational costs (supply of carbon dioxide, the removal of oxygen, pH-control, cooling, cleaning and skilled maintenance) in addition to significant capital investments.[5] Therefore, currently the most common methods of culturing algae are outdoor swimming pools and ponds.

After cultivation, for the collection of algae a variety of methods can be used, such as flocculation, filtration and centrifugation. Flocculation is an association of the fine particles into larger ones by biological or chemical action, and then they can be removed from the water. Filtering is a process that removes solids from the water, which is passed through a porous medium, such as sand or a special filter. Centrifugation is a process of separation of heterogeneous substances in density by using centrifugal force.

While the period of harvest can differ in various algae strains, they all tend to provide a plurality of harvests per year in contrast to most crops which are harvested once a year. The next step after algae harvest is it's handling, which usually involves drying. After that several components, such as lipids and oils are retrieved which are necessary for the production of biofuel. Algae biomass can be transformed into biofuel by chemical, biochemical or thermochemical conversion process or a combination of these processes.

Many world-known companies are currently engaged in finding ways of microalgae cultivation and the construction of various types of devices for these purposes. Among them are such well-known energy giants like Shell, ExxonMobil and Chevron, the companies-consumers of fuel Airbus, Boeing, Chysler, NextDiesel and even the companies for which the energy business is not the core - De Beers, Nestle and others. Theoretical studies and practical works are aimed at reducing the cost of the biomass obtained from microalgae. The volume of international publications and patent applications related to the production of biodiesel from microalgae is growing as well. Thus, the number of international publications increased from zero in 2003 to 256 in 2012 and international patent applications showed an increase from 5 in 2003 to 215 in 2012.

3. Materials and Methods

When analyzing the development of algal biofuels production in the world the methods of forecasting and benchmarking should be used. For more specific calculations, for example, to assess the necessary volume of land area, which should be given under the seaweed farm, to produce a given quantity of biofuels, economic-mathematical modeling methods, should be used. So as to assess the current state of affairs in the field of algae biofuels the fuel readiness level perspective management method should be used, which will be discussed in detail later in the article.

The global market of algae biomass production has the potential of explosive growth in the next 10-15 years. More and more investments are directed to the development of the algae industry in a number of countries. This specific area attracts increased interest from biofuel producers, petrol companies and agricultural business. In particular, the interest of USA and Europe towards microalgae is raised by the fact, that they are not able to grow enough amounts of corn, soybean, canola and camelina seeds to fully meet their needs in biofuel.

Different types of fuel can be obtained from algae is shown in Figure 1.

As for today bioethanol and biodiesel are of the greatest interest for the transport sector. Algae convert solar energy and carbon dioxide in the low-cost and highly productive raw material for food, biofuels, animal feed and high-value, and biologically active substances. In other words, these organisms have an effective solar energy bioconversion apparatus and are its natural bioaccumulations. The productivity of microalgae biomass exceeds the productivity of terrestrial plants.[6] Algae contain up to 200 times more oil than some first-generation biofuel sources, such as soy beans. As stated in the article, up to 200 barrels of oil can be obtained from 1 hectare of land allocated for algae cultivation.[7]

The US department of energy estimated that in order to replace all the petrol fuel in USA with alga fuel, about 39.000 square kilometers of algae farms will be needed, which is roughly equivalent to the area of Maryland state, or about 1/7 of the area used for crops.

The term "algae" refers to the set of unicellular and multicellular organisms composed of proteins, fats, carbohydrates and nucleic acids. Their percentage depends on the type of algae. There are several strains of algae almost ideal for producing third-generation biofuel, due to the fact that they contain larger amounts of oil. Currently, microalgae are the most promising type of algae for biofuel production due to the fact that they contain large amounts of oil.[8]

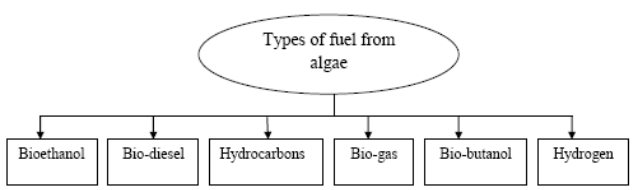

Figure 1. Types of fuel obtained from algae.

The microalgae potential energy yield is 8-25 times greater than in palm oil and 40-120 greater than in rapeseed, which allows them to be assigned to the typical representatives of oil seeds. Table 1 shows a comparison of the volume of oil produced from a unit area per year from various oilseed plants.[9]

As seen in Table 1, microalgae have a significantly higher yield of oil per ground unit area in comparison with other cultures. This may allow saving land resources and reducing the negative consequences from the usage of acreage for raw biomaterial growth with a view to its subsequent processing into biofuel.[10]

The technological process of biofuel production from algae is almost waste-free. Dry waste biomass retains all the vitamins and valuable substances after extraction of oil, and that is why can be used as feed in aquaculture and livestock farms. Here we list a number of potential benefits of biofuel production based on photosynthetic algae:

- the lack of need for large quantities of fertile land and fresh water;
- the possibility of growing in saline and polluted waters as well as on marginal lands;
- absence of competition with agriculture;
- the absence of need for fertilizers;
- high productivity of microalgae (up to 100 t / ha);
- high growth rate, outstripping the rate of growth of grain crops;
- a high content of oil in their biomass (to 70-85%);
- absorption of carbon dioxide in the process of biomass growth, reduction of greenhouse gases in the atmosphere;
- the molecular structure of the oil and biofuel derived from algae is similar to crude oil and petrol products;

Table 1. Volume of obtained oil per 1 acre (0.4 hectares) of soil from various plants per year

Plant	Gallons (3,8 liters) oil per 1 acre per year
Microalgae	700–7000
Oil palm	610–635
Jatropha	194–202
Rapeseed	122–127
Sunflower	98–102
Safflower	80–83
Camelina	60–62

- the derived from algae oil can be used to produce a wide range of fuels, including gasoline, diesel fuel and jet fuel.

Note that the fast-growing algae provide a very high biomass growth rate. With only one technological platform for the cultivation of algae for biofuel up to 40 harvest per year can be collected, and about 80% of all the organic matter generated daily on Earth falls specifically on algae. Despite that, seaweed which contains larger amounts of oil grows slower than the one that contains less amounts of oil. For example, algae containing 80% oil, grow once every 10 days, whereas algae containing 30% grow 3 times a day.

Amongst other things, the development of the algae industry or, as it can otherwise be called aqua-economy, can become a sort of job creating engine on a fairly extensive range of professions: from researchers to ordinary engineers, from biotechnologists to workers, from construction workers to farmers, from marketing specialists to financiers. According to experts, by 2020, the industry has the potential to create about 220 thousand new jobs. For comparison, as for today US algae industry employs about 10 thousand people. Prospects of development of the industry are seen to be very optimistic. For example, economists estimate that by 2018 the global turnover from the processing of microalgae biomass could be around 100 billion dollars.

3.1 Fuel Readiness Levels Methodic

A system of technical and production measurements of the readiness of possible ecologically efficient alternative fuels for aircraft which was called the fuel readiness level is also used in the USA. This system consists of 9 levels of readiness by analogy with well-known method Technology Readiness Level (TRL), and it was originally developed by the sponsoring organizations "Commercial Aviation Alternative Fuels Initiative"-CAAFI. This technique is a multi-step process of regulating the transmission of the technological readiness, readiness for qualification assessment, production and use of alternative fuel. Fuel system readiness level has two main functions assigned to it: information and management. The information function is related to timely inform of all interested parties about the current state of the process of developing alternative fuels. The management function is to have the ability to manage the process of developing alternative fuels, reducing the risks associated with its implementation. Approach fuel availability levels can be an important practical tool for the successful development and commercialization of algae biofuel. Currently, the production of algal biofuels is at the 6th-7th fuel readiness level. The 8th level can only be reached if successful commercialization can be as a fact, adoption of efficient biofuel production business models based on signed contracts for the sale and the environmental impact assessment of the manufacturing plant by an independent internationally approved methodology.

The search for effective approaches to the management of the process of creating biofuels from algae biomass is an urgent challenge both to government agencies and to private companies operating in the industry. There is a rapid growth of companies and organizations worldwide, which are working in the field of processing algae into energy, constituting in 2007, and two years later the number of units they exceed was more than 200, with a total budget of more than 3.8 billion dollars.[11] The key drivers for bioenergy development in many countries are the national energy, economic and environmental security.

4. Results and Discussion

By 2030, the volume of production of biofuels in the world can come close to oil production.[12] Herewith biofuel from algae could replace more than 70 billion liters of fossil fuel per year. The basis of this production may be algae biomass, which is now hardly used, or used with a low efficiency. This is due to the high cost of even simple algae production systems. For example, in a 2011 cost of production of aviation third-generation biofuels from algae grown in the Netherlands was about 28 Euro per liter, which was about 30 times more expensive than the cost of jet fuel. As for today, technologies for mass production of algae have not been developed yet, beginning from the selection of highly productive strains of algae that can be stably maintained in open water, and ending with the high cost of collection. However, according to the results of the 2014 survey of organizations working in the algae biofuel production field, more than 80% of responded believe that by 2020, the fuel derived from algae, is likely to be price competitive with traditional fossil fuels.

At present, the main task facing the algology (experts in algae), - the need to achieve significant productivity algal biomass with a high content of vegetable oils, which can afford to cover high capital and operating costs for the production of algae.[13] In addition, large-scale investments are needed for the construction of plants, preparation and organization of production, setup processes. Note that the potential application of advanced technologies in the cultivation of algae is not competitive in comparison with food and other crops, so that the efforts to overcome the existing obstacles and market barriers are justified.

In some developing countries with suitable climatic conditions (abundance of sunlight and water) as well as in some countries with developed market economies, there is an upcoming interest in the development of the algae industry. For example, Thailand launched a special project for microalgae in 2009. The project involved a lot of universities and independent researchers in Thailand. The main objective of the project is in the stable and successful commercialization of biomass and algae oil at competitive prices already in 2017, as a feedstock for biofuel production. The Malaysian Technology Park by efforts of Algaetech International SdnBhd conducted research related to the possibility of stably producing new-generation jet fuel at a competitive price.[14] Philippines conduct studies the production of microalgae raw biomaterial for economically profitable production of biodiesel.

The paper notes that commercially efficient mass production of biodiesel from algae is unlikely until 2020, despite the efforts of some countries to overcome the existing barriers.[15] For example, the US Department of Energy held a work seminar on technology road mapping of biofuels based on algae in December 2008. The purpose of this event was to study the ways of overcoming existing obstacles to the establishment of a strong commercial sector effective production of biofuels from algae. As a result, this led to the development and publication of the National technology road maps for the use of algae biofuels in 2010.[16] The main aim of this paper was to develop a formulation of the problem of algal biofuels to be competitive with petroleum counterparts. 5 basic areas of concern were identified on the way to the goal, where all the efforts and resources so as to solve the problem shall be directed:

- growing raw biomaterial for the industry;
- raw biomaterial logistics for the industry;
- the production of biofuels and other useful products;
- biofuel testing and standardization;
- sustainable practices in resource management.

The roadmap has made certain effect - by 2011 in research labs and demonstration plants, 44 US states actively developed innovative projects related to biotechnology and aquaculture cultivation.[17] By the end of 2011, about 65 companies which core business was the production of biofuel from algae were located in the USA. According to some estimations, at the period of 10 years, from 2000 to 2010, the private sector invested more than 2 billion dollars in the algae industry. According to the US Department of Energy, the amount of private investment in the development of biofuels from algae exceeds government funding in this direction.

The successful overcoming of existing barriers on the way to the mass production of algae biofuel could open a future possibility for producing economically viable fuel to the necessary extend, as well as for the needs of the aviation industry, which is a highly relevant perspective. In the upcoming years the demand for aviation fuel, according to Airbus experts, will continue to increase: by 2035 more than 37,000 commercial passenger jets will be used, which is about two times more than now.[18] This will lead to a shortage of petrol, strengthening the greenhouse gas emissions and the overall negative impact on the environment, and therefore the demand for aviation biofuels will grow, especially with a gradual decrease of its price in the market.[19] Thus, the International Air Transport Association (IATA) has made the assumption that by 2020, 6% of all aviation fuel used in the world, can be obtained from renewable alternative sources.

4.1 The Perspectives of using Algae Biofuel in Aviation

Aviation biofuels produced from renewable sources, that is microalgae, has been successfully tested in both commercial and military aircraft and has been approved for use in commercial flights. Some airlines with a worldwide reputation successfully conducted test flights using microalgae biofuels as an integral part of the fuel mixture. Here is a brief history of the use of algae biofuels for aviation. In 2009 Continental Airlines in the United States held the world's first test flight of a commercial aircraft using algae biofuel as part of the fuel mixture. Flight on Boeing 737 aircraft was made from the Houston International Airport. One of its two engines was working on biofuel mixed with conventional fuel, thereby marking the beginning of a new era of biofuels from algae for aviation needs. In 2010 the European Aeronautic Defense and Space group (EADS) conducted the world's first test flight of the Diamond DA42 New Generation aircraft with the usage of 100% reactive algae fuel. The fuel was granted by the Argentinean manufacturer Biocombustibles del

Chubut. Due to possessing more energy, fuel consumption was reduced by one and a half liters per hour compared with the conventional fuel JET-A1. The amount of carbon dioxide released into the atmosphere during the flight turned out to be approximately equal to the volume of the absorbed carbon dioxide in the process of initial biomass growth of algae. This makes it possible to talk about the feasibility of carbon-neutral flights. In June 2011, the US Navy successfully demonstrated a mixture of traditional fuel and fuel from algae, produced by Solazyme, in a 50-50 proportion in the MH-60S Seahawk multi-purpose helicopter. It was the world's first military aircraft flight using biofuel from algae. In November 2011, United Airlines launched flight 1403 (from Houston to Chicago) on a 40% mixture of algae jet fuel produced by Solazyme.[20]

4.2 The First Major Agreements and Transactions

Currently, many companies are working on obtaining bioreactive fuel from algae, such as Sapphire Energy, Heliae, Phycal, Cellana, General Atomics, Aquaflow Bionomic Corp., Algenol Biofules and others. Some airline companies and aircraft manufacturers are already showing interest in third-generation biofuel. Thus, the Boeing company made a statement about the production of aviation biofuel from marine microalgae. According to Boeing experts, biofuels from algae is the future of aviation.[21] United Airlines has signed an agreement with Solazyme company to buy 20 million gallons of jet fuel from algae per year. Solazyme became the first algae production company which received a license for the production of jet fuel from algae from the American ASTM certification organization. By 2009, the company managed to attract a total of over 70 million dollars of investment, with the key investor being Chevron. In 2010, the company already had a factory built for commercial purposes. Construction of the plant can be explained by the presence in the US of a demand for fuel from algae, even though its current high cost. So, in 2009, Solazyme sold 20,000 gallons of biofuel from algae for 8.5 million dollars ($ 425 per gallon) US Naval fleet. In 2010, the company sold another 150,000 gallons for the price of 10 million dollars ($ 67 per gallon). The price per gallon of fuel was reduced due to the fact that the cost of the product did not include the initial cost for research and development. The cooperation on the development and production of algae biofuel was also strengthened in Europe. For example, the Dutch airline KLM has invested in the company AlgaeLink, which is engaged in the cultivation of algae. The size of the investment was not mentioned. Currently, the two companies are actively collaborating on the development of the next generation alternative aviation fuels. A technological roadmap for the period of the next 5-15 years as the sequential turn-based strategy for further development of the aviation fuel sector has been composed. Both the existing ways of improving fuel efficiency and possible new alternative fuel types for the aviation industry were taken into account. In addition, basic technology that proved the technical feasibility of the production of alternative aviation fuel was demonstrated. AlgaeLink specialists presented the world's first highly efficient demonstration plant as well as the fully automated industrial photobioreactor for mass production of microalgae under controlled conditions. Some companies predict a significant increase in demand for bio-diesel and jet fuel from algae in the near future. In this regard, the Sapphire Energy company, located in San Diego, California has set the ambitious goal to produce 100 million gallons of bio-diesel and reactive fuel from algae by 2018, and another 1 billion gallons by 2025. The company has received about 100 million dollars of investment from Bill Gates and the Rockefeller Foundation.

4.3 Role of the US Military Sphere in the Development of Algae Biofuel

An interest in aviation biofuels from algae is exhibited by the military. For example, the US Air Force has high hopes for the success of the experiments with biofuel from algae, as it can help to provide a more economical operation of military aircraft. The US militaries hope that this fuel can not only fill the jets, but also vehicles of the ground forces. In this regard, Defense Advanced Research Projects Agency (DARPA) along with the Science Applications International Cooperation (SAIC) and General Atomics company engaged in the development of an economically viable military jet fuel grade JP-8 from algae. The Honeywell company, UOP recently launched a project to produce military jet fuel from algal and vegetable oils. The US federal government encourages the development of alternative fuels, pursuing the goal of reducing greenhouse gas emissions from aviation, support sustainable economic development and ensure the energy security of the country. To help ensure compliance with the requirements to reduce greenhouse gas emissions, the aviation industry in the United States actively supports the development of alternative jet fuels. Interestingly, according to the report of the General Accounting Office, the Pentagon bought algae jet fuel at the price of 150 dollars per gallon, while the price of a traditional jet fuel was approximately 3 dollars per gallon.[22] An additional 147 dollars was paid in order to subsidize the industry. According to a study conducted by experts of the Federal Aviation Administration (FAA), in 2020, the production on a commercial scale alternative jet fuels by the method of Hydro processing Esters and Fatty Acids (HEFA) will require a subsidy of between 0.35 and 2.86 dollars per gallon, in order to be competitive in price with conventional jet fuel. A more interesting statement was made by DARPA, which stated that they will soon be able to transform algae into biofuel at a price that competes with fossil fuels. The statement made by the agency, which helped at the time to develop the Internet and satellite navigation systems, openly surprised many in the industry. According to the statement, the price of 1 gallon of algae jet fuel is less than 3 dollars. Note that, as for today, DARPA experts are capable of receiving microalgae oil for 2 dollars per gallon. As for now, research efforts aimed at further reduction of price down to 1 dollar per gallon.[23]

4.4 State Study of Microalgae in The United States and The International Cooperation Development

In the USA a number of national laboratories carry out research in the field of algae biofuel which is funded through government funding programs. Some of these laboratories are: National Renewable Energy Laboratory, Sandia National Laboratories, National Energy Technology Laboratory, Los Alamos National Laboratory, Pacific Northwest National Laboratory and Oak Ridge National Laboratory.

The most complex program of algae research in the US was a program financed by the US Department of Energy called “The Aquatic Species Program” in the period from 1978 to 1996. During this period, the US Department of Energy has invested more than 22 million dollars in study the variety of algae species that can be used in the production of renewable energy. Based on the study results, scientists concluded that California, Hawaii and New Mexico in particular are the most suitable for the industrial production of algae in open ponds due to their natural and climatic conditions. The cooperation between countries on the development of aviation biofuels from algae is also developing. Thus, Lufthansa airlines announced in January 2013 its intention to invest in the best Australian biotech company Algae Tec. The two companies decided to implement a joint project to build a factory in Europe for large-scale production of biofuel from algae for aviation. The factory will be located near an industrial facility, carrying carbon dioxide emissions. This project will be financed by Lufthansa under the condition that, according to the long-term contract it will be guaranteed a fixed-price purchase of, at least, 50% of the produced liquid biofuel.

In 2012, Airbus, EADS and leading Chinese company ENN Bioenergy signed a partnership agreement to assess the potential development of alternative aviation fuels based on algae oil produced in China. Experts predict that by 2030, China’s domestic demand for oil can reach the mark of 15 million barrels per day. At the same time the oil production site is supposed to be able to meet only about 20% of the total demand for it. In this regard, China’s task for 2020 is to ensure at least 15% of transport energy needs through the production of more than 12 million tons of biofuel. Microalgae can become one of the most promising sources of biological raw material for such a production. This cooperation involves the technical qualifications of the fuel and its promotion for use in China Aviation, which is currently one of the fastest growing aviation markets in the world. ENN has developed a project and it has build one of the most advanced demonstration plants in the world, which is able to produce more than 10 tons of algae oil per year, based on it.[24] During the initial stage, the partners will be working on the evaluation of the maturity of the oil extraction technology from algae, the testing of the oil with further analysis and development of tools for evaluating the environmental, economic and social impact of such technologies.

Cooperation between the United States and Mexico in the field of biofuel production from algae is developing. So, the American company OriginOil supplied Mexico with operational capacity which allows the production of 1% of fuel for the jet engines of the country, using algae as a source raw biomaterial. By the end of the decade, this figure is projected to reach 20%.

4.5 The Problem of Economic Profitability of Biofuel Production from Microalgae

A relatively small area of land across the Earth is needed so as to provide a global demand of algae aviation fuel.

So, Boeing's experts estimate that if the fleet of all airlines in the world as of 2004 was to only use algae biofuel, it would need 322 billion liters of oil per year. One hectare can provide 6500 liters per year. From this we can calculate that in order to grow the required amount of algae 50 million hectares of land would be required. For comparison, approximately the same area is needed to only provide Russia with an annual demand for aviation fuel, if an oil plant like camelina is used entirely. The difference is obvious and enormous. By the volume of oil produced per unit area of algae can exceed the camelina in more than 100 times. Besides, a land that is unsuitable for growing food crops can be used for the cultivation of microalgae.

However, despite the significant investments made by various private companies and government agencies in the development of biofuels from algae, no suppliers are currently engaged in a commercially effective production of algal biofuels on a large scale. Therefore, the full-scale use of biofuels from algae in the aviation industry is economically inefficient due to the lack of development of such fuels production. At the same time, the existing algae industry (the strongest in the United States, Australia and Israel) produces about 10,000 tons of dry algae per year, mostly used for the production of paint, fish food and various food additives.

The high cost of cultivation, harvest and processing of algae is a significant barrier to the commercialization of algae biofuel. So, a study conducted in 1989 showed that the cost of biodiesel from algae was 6 dollars per liter, which is 10 times higher than the price of gasoline. Modern technologies allow reducing production price down to 3 dollars, yet it is still insufficient in terms of economic efficiency. Algae biofuels can become more competitive, in case of an increase in world prices for fossil raw materials (oil and gas). But it has a con as the cost of algae production may be increased more by increasing prices for building materials, energy and nutrients.

Products with a higher market value than fuel can be obtained from algae. If necessary for this substance can be extracted from algae, while not interfering with fuel reception, and in the presence of strong demand for the markets and products obtained, this may allow reducing production costs of biofuels. Let's list some basic products which can be obtained from algae in addition to fuel:

- feed for animals, birds and fish;
- food and nutritional supplements;
- chemical raw materials for industry;
- cosmetics and sunscreens;
- pharmaceuticals;
- fertilizer.

The above mentioned products are produced based on algae, have a great market potential, and a large number of companies strives to find its niche in these promising areas.

The cost of algae biofuel could also be reduced if using the algae growing biomass for cleaning wastewater that may contain phosphates and nitrates, which are essential nutrients for algae. These substances can be dangerous if they enter the watercourse, promoting algal blooms in lakes and rivers. Using algae to absorb these harmful substances will reduce the cost of their cultivation, as well as get some income from the water purification process.

The world is on the verge of an unprecedented water crisis. According to UN estimates, by 2025 two out of three people will not have access to clean drinking water. Water scarcity can be a key limiting factor for the production of vegetable raw materials for further processing into biofuel.[25] Microalgae are promising raw material for biofuel production, as they consume less water than some other plants. For example, to make one gallon of soybean biodiesel 15,600 gallons of water are required to be spent, canola (rapeseed special grade) requires 5810 gallons, while microalgae require only 300 to 1000 gallons.[26] In addition, there is a possibility to use sea water or contaminated water for the cultivation of microalgae, which also will help maintain clean drinking water.

4.6 Russia's Experience in Microalgae Investigation

The biofuels market in Russia could grow by more than 1.5 times up to the level of 5 million tons per year by 2020. Russia as well as some other countries is already developing third-generation biofuel. Even at the times of the Soviet Union in 1985, Russian scientists have provided a ready for installation device for retrieving of methane gas from algae. The unique setting is saved in the Scientific-Production Association "Biosolyar State University". In 2008-2010 Federal State Unitary Enterprise "Waterworks" were carried out work on the production of algae biomass biologically purified water and processing it into biofuel. Basic technological stages were worked through, displayed stable biocenosis of algae, which gave optimal growth in the purified water, developed technical solutions for the creation of the photobioreactor.

As for now, specialists of the Novosibirsk State University are working in conjunction with the Institute of Catalysis SB RAS, developing catalysts and reactors for the third-generation microalgae biofuel. Biologists and chemists from Novosibirsk look for intensive ways through the improvement of the process of catalysis, and other technologies, fuel extraction of raw materials from algae.

Most of the existing approaches to the cultivation of microalgae require a large amount of sunlight and temperature to obtain a stable high yield during the year. Therefore, for the cultivation of microalgae Russians should think about opening strains of algae that could grow at relatively low temperatures and light deficiency. Special attention must also be paid to the development of technologies that will protect the microalgae from freezing. In the meantime, it should be stated that in the event of domestic demand in algae biofuel in a considerable amount, Russia has to rely on imports. The main driver of the development of biofuels from algae is still the environmental policies of developed countries to minimize the extent of environmental pollution.

5. Conclusion

It is most likely that in the future significant scientific and technological breakthroughs will be required so as to make algae biofuel commercially attractive. Currently, most of the fuel cost of production falls on the cultivation and harvesting of algal biomass. A negative factor for the successful development of biofuels from algae, in particular jet biofuel, was the fall in world oil prices, which began in mid-summer of 2014. This resulted in a reduction in jet fuel prices.

However, microalgae have a number of significant advantages over many vegetable crops, which are considered as a source for biological raw material. In the case of overcoming the currently available objective obstacles to successful commercialization and mass use of biofuels from microalgae, they can become a kind of energy source of the future. Liquid motor fuel production from algae biomass is currently technically feasible. Nevertheless, there is a need to introduce a number of innovative solutions at all stages of production of biofuels based on algae to eliminate its technical and economical inefficiency, which represents a significant challenge to the viability and the successful development of large-scale commercial enterprises engaged in the production of biofuels from algae on a large scale.

Eventually, after the long period of development, algae biofuel has the potential to become an economically attractive alternative to traditional fossil fuels with less negative impact on the ecology of the environment. According to experts, the probable date of maximum manifestation of the technological trend will be at about 2025-2035 years. Formation and development of biofuels from algae can seriously affect the development of economy and society in the long term in Russia and in the world. This statement is true for the global market for civil aviation as an integral part of the modern world economy.

6. References

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