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Biofuel Energy in the Post-oil Era

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ABSTRACT

The article proposes evaluating the costs of bioenergy supplies in Russia utilizing a method that is based on energy analysis. The main disincentivizing factor is not as much limited resources as the marginal cost of producing biofuels and the possibility of using cost-effective ways of reducing greenhouse gas emissions, including carbon capture and storage, alternative forms of renewable energy, energy efficiency and energy savings. In this situation, the possibility of progressive development of the global market for biofuels can only be achieved by fundamental changes in the industry, that are determined by the peculiarities of scientific progress. The author also identifies several technological, economic, financial and natural factors constraining large-scale advances in bioenergy. Comparing innovation policies of various countries of the world and paper notes of industrialized countries, we can see a high level of R&D investments in the field of biofuel technologies.

Keywords: Energy Sources, Biodiesel, Fuel Butanol, Fuel Ethanol
JEL Classifications: C30, D12, Q41, Q48

1. INTRODUCTION

Nowadays, 80% of humanity's energy industry is based on fossil fuels - oil (35%), coal (46%) and gas (20.5%). Because of this, motor fuel (gasoline and diesel fuel) is almost entirely obtained from oil.

There are several good reasons why the current situation should be changed. Firstly, fossil fuels are finite, although estimates for when these resources will be exhausted are mixed; it's about 40-60 years for oil, 70-90 years for gas and 150-200 years for coal.

Secondly, the burning of huge amount of fossil fuel leads to an increase in the concentration of carbon dioxide in the atmosphere, which causes the "greenhouse effect" and global warming. High oil prices are also a powerful economic factor that contributes to the development of an alternative biofuel industry.

These global problems should be solved by using renewable energy sources. In all developed countries, there are long-term plans for the use of wind, solar, plant biomass, and geothermal energy. Intensive research and development work should be launched in these areas. A legislative framework has already been created to facilitate innovation in them.

Ethanol and biodiesel types of fuel are already widely used as motor biofuel. It is planned that 30% of traditional motor fuel will be replaced by biofuel in the USA and 25% in Europe. Ethanol is primarily used in the USA, whilst Europe chooses biodiesel.

This article is devoted to the review of the prospects of using plant biomass to produce motor fuel. The most appropriate fuel, ethanol, is hygroscopic, i.e., it adsorbs moisture from the air, therefore its transportation, storage and mixing with gasoline requires special equipment.

The main producers of ethanol are Brazil and the United States. Ethanol fuel production in Brazil was launched in the 1970s in connection with the first oil crisis. The state has introduced new fuel standards, established subsidies and incentives for producers of ethanol fuel and modified cars. The program has been very successful. Today Brazil is the largest (after the USA) producer of ethanol, with 13 million tons in 2006.

2. LITERATURE REVIEW

Since 2004, production has become profitable even without subsidies. Not only do ethanol plants in Brazil not consume energy when producing alcohol, but they even produce electricity. After squeezing sugarcane, the sugar-containing juice undergoes fermentation, and the solid residues serve as fuel to produce steam. The amount of this steam is enough to distill the alcohol and obtain additional electricity (Morris and Barlaz, 2011).

Price indicators of the production of ethanol from reeds, obviously, are unattainable when using other raw materials. The low price of Brazilian ethanol, together with its constantly growing production, as well as the possible organization of production in other countries which grow sugarcane, should be considered when planning global markets for ethanol fuel. Thus, the Japanese market will be almost completely provided with ethanol from Brazil (Chiemchaisri et al., 2012; Gardner et al., 1993).

The largest ethanol producer is the United States. In 2007, its production amounted to 16.5 million tons (Jaramillo and Matthews, 2005; Wustenhagen and Bilharz, 2006).

The United States and Brazil jointly produce more than 70% of ethanol in the world. The Russian Federation ranks 6th in the world in ethanol production (650,000 tons in 2005), behind the USA, Brazil, China, India and France (Bove and Lunghi, 2006; Cai et al., 2011).

In recent years (2004-2007), the commissioning of ethanol production facilities in the United States amounted to about 2.5 million tons per year. But the program that initiated this process stipulated that due to the increase in the yield of corn, the share of crops processed into ethanol would remain constant. But this prediction was incorrect. There is an increase in the share of corn processed for fuel ethanol (11% in 2004 and 14.5% in 2006).

According to many economists, a sharp increase in grain and, simultaneously, food prices is associated with an increase in grain consumption during the production of ethanol, oil and also biodiesel (Milbrabdt et al., 2014; Morgan and Yang, 2001).

Can ethanol completely replace gasoline in the medium term? Obviously not in the conditions of the material base and the existing design of internal, low efficiency combustion engines. In fact, about 400 million tons of gasoline are consumed annually in the USA. In 2007, 16.5 million tons of ethanol were to be produced in the country, which, given its lower energy content, is equivalent to approximately 10.7 million tons of gasoline (Ahmed et al., 2014; Mikhaylov, 2018b; Nyangarika et al., 2018).

Thus, for the complete replacement of gasoline, the United States would need to produce about 600 million tons of alcohol, which would require 1560 million tons of corn, i.e. 7 times more than the total harvest in the USA (Amini and Reinhart, 2011; Bansal et al., 2013).

In Europe, sugar from sugar beets or cereal grains can be used to produce ethanol. The cost of ethanol from beets is even higher than from corn. 2.6 kg of corn or 3.2 kg of wheat are consumed per 1 ton of ethanol. About 50% of the cost of ethanol is the cost of raw materials. In 2006-2007 there was a sharp jump in grain prices. If, until 2007, ethanol production was cost-effective due to an oil price of about 50 USD per barrel, then now the price is at least 75-80 USD per barrel (Nyangarika et al., 2019b; Nyangarika et al., 2019a).

So, a new ethanol-producing plant in England with a capacity of 100,000 tons of ethanol fuel per year, commissioned in 2007 uses wheat as raw material.

Therefore, a substantial increase in food-based ethanol production is not possible. Of course, some growth will occur due to increased yields, especially when considering the removal of genetically modified plants. Corn plants with an increased yield of 20-30% or with a modified starch structure have already been obtained, which helps counteract scarcity. But the consideration of different ways to improve plants is not an objective of this article. An interested reader can find information about such developments in other reviews.

The principal reserve for large-scale production of ethanol fuel is a non-food raw material - lignocellulose.

With the implementation of this process, the raw material base for producing ethanol fuel is greatly expanded and, most importantly, its production is not related to food production (Denisova, 2019; Denisova et al., 2019).

In the framework of this discovery $2.9 billion were allocated up until 2012 to support research and development of scarification (a special procedure in botany) technology of the lignocellulose. Another $1 billion is allocated to support the construction and operation of pilot plants. Two such pilot plants with a capacity of 10,000 tons of ethanol fuel were launched in the USA in 2007. According to the plan, 1.5 billion gallons of ethanol fuel were to be obtained using lignocellulose in the USA in 2015 (Mikhaylov, 2018a; Mikhaylov, 2019).

The production of ethanol fuel, as already mentioned, is carried out with the aim of replacing fossil fuels, reducing carbon dioxide emissions into the atmosphere. And there are also political reasons: The United States would like to reduce its dependence from Middle Eastern oil. There are socio-economic motives associated with increasing the income of agricultural producers (marketing straw, etc.) and the organization of new jobs in the new and developing biofuel industry.

Fossil fuels contribute to carbon dioxide emissions. But fuel energy (and mainly fossil fuel energy) is also spent on growing agricultural plants (plowing, fertilizing, cleaning, transportation, storage), scarification of raw materials, distillation and dehydration of alcohol. The energy stored in alcohol only slightly exceeds the energy spent on its production from plant materials (for 1 unit of energy consumed, 15 units stored in alcohol are obtained). Thus, the use of ethanol instead of gasoline reduces carbon dioxide emissions by only 12%.

Another negative environmental consequence of obtaining alcohol from plant materials, corn in particular, is soil depletion and environmental pollution by pesticides during intense cultivation. The expansion of agricultural crops in Brazil, including sugar cane, leads to the destruction of tropical forests, which already causes protests of the world's communities (Meynkhard, 2019; Lopatin, 2019).

In any case, alcohol-based fuel is already a fact of modern industrial production. There is no doubt that in the next 1-5 years, this type of production will develop rapidly not only in North America, but also in Europe, especially its Eastern countries, and in some states in Latin America. China and India, whose main task is to feed their huge population, are unlikely to use raw food goods for biofuels, but it is likely that they will develop this production based on non-food resources.

China plans to produce only 2 million tons of ethanol from lignocellulose by 2020. Over the past year, China has built several plants for the hydrolysis of plant materials on the border with the Russian Federation, which uses its neighbor's waste from processing wood supplies.

3. METHODS

Mastering the process of obtaining ethanol from cellulose requires a large and coordinated effort of various specialists. It is, of course, about economically viable production. The Russian Federation has access to ethanol production that is based on acid hydrolysis of plant materials, which was created back in the 50-60s. But it is not viable today due to its price and environmental complications.

Environmentally friendly production requires the improvement of all stages of the process in its entirety, starting with the plants themselves. These changes concern not only the yield, but also the quality of starch, the decrease in lignin content and the intensification of the biosynthesis of enzymes that hydrolyze starch and cellulose in the plants themselves.

The use of plant enzymes for scarification of starch is not new (malt is a sprouted grain that has been used for scarification of starch in brewing for millennia). Unfortunately, plants that provide cheap enzymes have not been discovered yet. So microbial enzymes are currently used in industry. Over the past 5 years, tremendous progress has been made - prices for microbial celluloses have been reduced by 20 times, but they are still quite high.

Attempts are being made to create yeast that would secrete the necessary enzymes into the medium, and thus the hydrolysis of polysaccharides and the fermentation of sugars into alcohol would be carried out in one process. However, all these studies have not yet left the walls of laboratories.

The composition of lignocellulose hydrolysates is rather complicated. These hydrolysates contain not only glucose, arabinose and xylose as its main components, but also (in small quantities) other sugars, organic acids and other compounds, some of which inhibit the vital activity of microbial cells. Conventional wine yeast does not absorb xylose well. Hundreds of tests, trials and experiments have been performed to improve this property of yeast using both classical selection methods and genetic engineering methods.

The best microorganism in this regard today is the Saccharomyces cerevisiae strain, which introduced the xylose utilization genes from Pichia's pastoris years. This strain increases the yield of ethanol by 40% with growth on lignocellulose hydrolysates when compared to the original yeast strain, which does not absorb pentoses.

4. RESULTS

In the United States and Europe, efforts are being made to concentrate scientific efforts into the development of scarification technologies for cellulose. Thus, in the 7th framework program of the EU, funds for the development of renewable energy increased by 50%.

We have already mentioned the efforts of the United States under the Energy Policy Act. Interestingly, large international oil companies are also interested in developing the scientific foundation of biofuel technology. For example, British Petroleum has $500 million ready to be financed in new scientific studies in Yale Center, organized on the basis of the University of Berkeley (California, USA), as well as the work of national laboratories, Lawrence (LBNL - Lawrence National Laboratory) and the University of Illinois (Urbana-Champagne).

Firms Shevron and Conaco Philips also started to finance the development of biofuels, mainly based on lignocellulosic feedstocks. However, the scale of financing is still small (tens of millions of dollars).

Thus, we can assume that in the medium term (about 7-8 years), bioethanol production in the world will grow rapidly based on the use of agricultural plants: sugar cane in Brazil and other tropical countries; corn in the USA; wheat, rye, barley in Canada, Australia, Eastern Europe and the CIS countries (Figure 1).

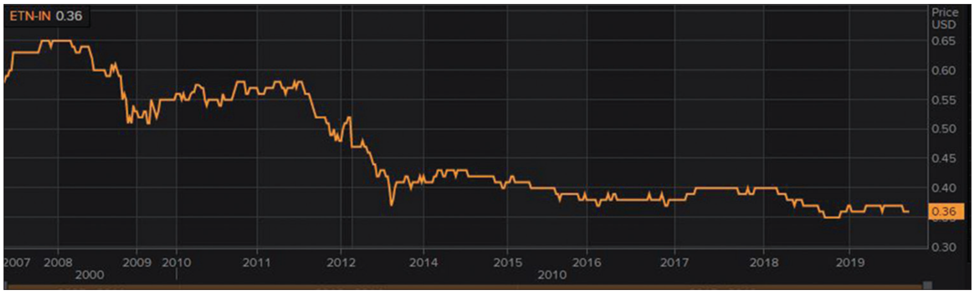
Technologies for cost effective production of biodiesel fuel from fatty acid, rapeseeds, soybeans and palm trees are expected to be developed in the next 5-7 years (Figures 2-5).

If it is possible to sufficiently reduce the price of ethanol from plant materials, it can be used not only as fuel, but also for processing into ethylene, polyethylene and other compounds, replacing petrochemical products in this sector.

The technical properties of biodiesel are very close to the properties of the diesel fuel that is derived from oil.

In Europe and Canada, you get biodiesel from rapeseed oil, in the USA – from soybeans, in Malaysia and Indonesia - from palm oil. The properties of biodiesel depend on the fat and alcohol used for esterification. Therefore, in the case of isopropyl alcohol, you can get biodiesel even at freezing temperatures.

Figure 1: Indian bioethanol price

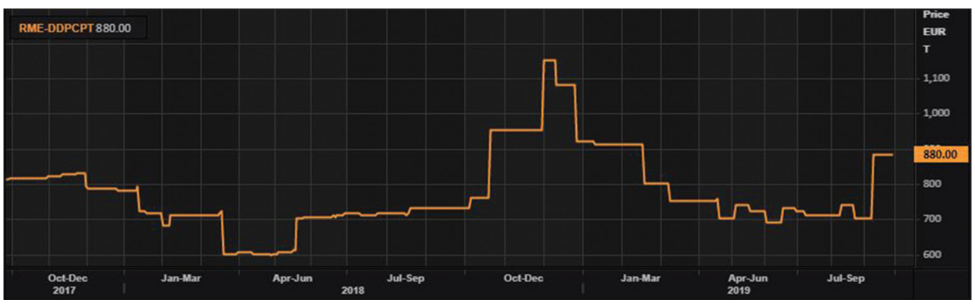


Source: Thomson Reuters

Figure 2: Fatty acid methyl ester biodiesel price

Source: Thomson Reuters

Figure 3: Rapeseed oil methyl ester biodiesel price

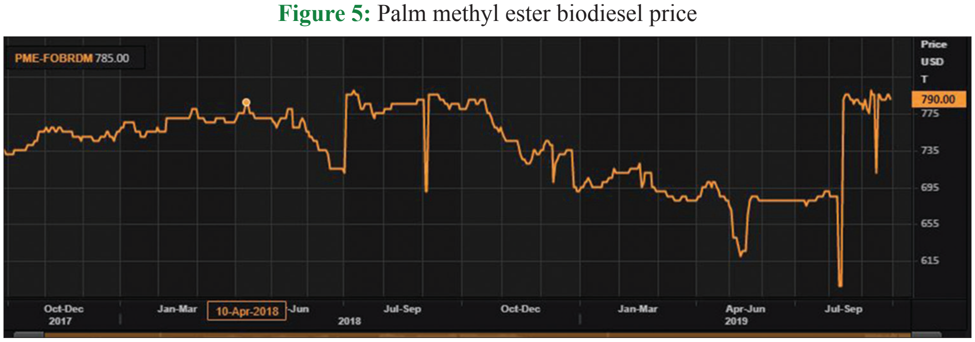


Source: Thomson Reuters

Figure 4: Soybean methyl ester biodiesel price

Source: Thomson reuters

Figure 5: Palm methyl ester biodiesel price



Source: Thomson Reuters

World production of biodiesel, mainly from rapeseeds, amounted to 9.7 million tons in 2006 (2.5 tons of rapeseed are consumed per 1 ton of biodiesel). 19.5 million tons of rapeseed are planned to be produced in the world from 2007 to 2008, 17.45 million of which will be from Europe. Today, the main producer and consumer of biodiesel is Europe, where it is made almost exclusively from rapeseed oil. Although biodiesel production in the United States is incomparably lower than in Europe, it is growing rapidly (from 2 million gallons in 2000 to 250 million gallons in 2006).

In this country, soybean oil is used as a raw material at a higher cost. A number of reviews are devoted to this topic. The price of glycerin is lower than the price of glucose obtained from starch, and it can be used as a raw material in microbial synthesis. Microbial synthesis products may include ethanol, succinic acid, 1,3-propanediol and many other useful substances. The theoretical yield of ethanol when using a carbon source for the cultivation of microbes' glycerol can reach 95% and its cost can be 40% lower than when obtaining ethanol from grain.

Palm oil has a lot of potential for biodiesel production. In the countries of its cultivation (Indonesia, Malaysia), there are extensive biodiesel production plans.

For the economy of biodiesel production, the processing and marketing of related products – rapeseed and glycerin is important. The use of rapeseed meal is not a problem, as it is a complete feed with a high protein content (about 25%), which successfully replaces soybean meal in feeding farm animals.

Currently, the United States has a plant that produces 1,3-propanediol using microbial synthesis from glucose. But the cost of the product obtained is much lower than in chemical production.

Methods of production of butanol, propionic acid and succinic acid from glycerol are being developed.

From the 1920s until the end of the 1950s, milestone butanol was obtained using microbial synthesis, which uses flour and molasses as raw materials.

In recent years, a lot of work has payed off and considerable success has been achieved in improving the properties of microorganism strains producing butanol, as well as in improving the corresponding technological process.

There is a method of thermal gasification of plant biomass - its conversion into synthesis gas, consisting of carbon monoxide. It is transformative and difficult to convert to sugar in certain plant biomasses. The process of catalytic conversion of synthesis gas into liquid hydrocarbons has been known for a long time.

5. CONCLUSION AND DISCUSSION

The Russian Federation has unique potential for the development of the biofuel industry. Arable land of the Russian Federation makes up 10% of the world's arable landmass with a population of 2.4% of the world population. About 25% of the world's forest reserves are concentrated on the territory of the Russian Federation. However, these potential opportunities for their implementation require tremendous efforts and, of course, state support. Rather, not even support, but state will, which is implemented in the form of a long-term program and powerful financial support, since it is about creating elements of the future economy.

One of the main obstacles to the development of biofuel production is the country's backward agriculture. However, the productivity and cost of production in agriculture are not always inversely proportional factors. So, the grain yield in the United States is almost 2 times less than in Europe, and the cost of grain is lower. The biofuel industry, creating a constant and steady demand for grain, will help maintain fair prices and thus stimulate agricultural producers.

This resulted in the decommissioning of approximately 15 million hectares of arable land. The state was forced to buy grain at stable prices to maintain the market in 2003-2006. However, in 2007, grain prices in the Russian Federation almost doubled and the state sold grain to control them. In fact, the established grain prices were fair; they enabled agricultural producers to recoup costs and have the means to develop production (Mikhaylov et al., 2018; Mikhaylov et al., 2019).

But unfortunately, grain exports from the Russian Federation is a temporary and rather unnatural phenomenon. The state cannot feed its population and imports a huge amount of food (meat is imported up to 40%). In recent years, domestic poultry and pig farming has developed quite rapidly.

If grain production in the country remains at 70-80 million tons per year, then it will not export, but import it. The solution is to double grain production to 140 million tons per year. Developing and executing a nationwide program of the revival of agriculture in the central regions of the Russian Federation will help overcome enormous challenges. Within the framework of this program, roads, storage facilities and enterprises for processing agricultural products should be built, new settlements should be founded, etc.

At the first stage of the "wet" process, protein (gluten) is extracted from the grain, and the remaining starch is scarified and fermented into alcohol. Gluten is a valuable, high-protein product. Adding gluten to low-grade flour improves the quality of bread, both nutritious and organoleptic. The price of gluten in Europe is about £1000 for a ton.

The issue of cost-competitive production of ethanol is hardly discussed at conferences of the Fuel Association, and this is exactly one of the biggest problems. More than 200 distilleries operate in the Russian Federation. The price of grain in the country has risen sharply. If in 2007 grain in England was worth $400 for a ton and $270 in France, then in the Russian Federation the price was about $150-170 for the same amount of product.

On the foreign market, the Russian Federation may face competition, especially from other CIS countries and Eastern Europe.

Since 2003, Ukraine has been implementing a program to increase rapeseed production; in 2007, 1.2 million hectares were already sown with rapeseed. In the coming years, it is planned to sow up to 3 million hectares (a more probable forecast would be 1.5 million hectares).

Belarus is building two powerful plants to produce ethanol fuel, capable of processing up to 3 million tons of grain.

Since the Russian Federation has not created a legislative framework for the use of biofuels, all plans are related to the export these products.

It is clear that the production of ethanol fuel should be free of excise duty. It is most rational to solve the issue of excise duty individually for new large plants where control is easier.

Tax incentives or direct subsidies are needed to develop the biofuel industry. For the Russian Federation, it would be more appropriate to subsidize grain processing products than to bring down grain prices (Morozko et al., 2018a, Morozko et al., 2018b).

A big challenge for world science and technology is the development of economically feasible ways of scarification of lignocellulose and the development of the biofuel and chemical industries based on these renewable raw materials, the product of which is gradually replaced by oil and gas.

Russian Federation can remain the leading energy power in the post-oil era, thanks to its huge reserves of forest and agricultural land.

It's not too late for the Russian Federation to join the global race to create an economy based on renewable resources. A problem of this magnitude, one that is global, multidisciplinary scientific and technical cannot be solved by the method of grant distribution on a competitive basis. The available scientific and technical potential is clearly not enough, and it is scattered across different organizations. Perhaps, the time has come for the Russian Federation to solve an important problem - the creation of new research organizations with a powerful experimental base.

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