ASSESSMENT OF BIOFUEL PRODUCTION TECHNOLOGIES FROM MICROALGAE AND ORGANIC WASTE

Introduction

Today, the processing of organic matter, such as organic waste or microalgae, is an important way to renewable energy sources. To maintain a prosperous life of the population, it is critical that renewable sources of energy be found. While it is important for energy to be produced without harmful emissions and long-term damage to the environment, it is equally important for the form of energy to be reproducible over extended periods. Biofuels are a form of renewable energy by the fact that they are generated in shorter cycles, as compared to the geological processes required to generate fossil fuels [1].

Problem statement

Because mineral and organic energy reserves in the near future will no longer meet the ever-greater and greater energy needs of mankind. New technologies are already emerging around the world that allow the production of organic biofuels based on many plant species and waste. However, the cultivation of crops, on the basis of which in the future will produce biofuels, leads to depletion of land resources. Simply put, the thin layer of fertile humus as well as the top layer of humus is gradually depleted, which can lead to the decommissioning of millions and billions of hectares of arable land. Thus, the development of technologies that involve expanding the raw material base for biofuel production becomes obvious [2].

Analysis of previous research

A decade ago, the green technology space was alight with the energy potential of algae. Fuel derived from algae, dubbed the ‘third-generation biofuel’, holds several key advantages over earlier feedstocks based on plant crops such as sugar cane and corn (the first generation of biofuel production) and vegetable or animal waste streams (the second). These algal advantages include higher biofuel yields compared to previous systems, a diverse list of possible fuel types including biodiesel, butanol, ethanol and even jet fuel, as well as the fact that large-scale algae cultivation — whether in open ponds or more advanced closed-loop systems — can be done on land unsuitable for food crops, removing a key concern that biofuel feedstock crops would compete with food producers. One more advantage of algae can be considered that they, unlike the cultivation of other plant materials, do not need fertilizing. For their full growth, algae use only carbon dioxide (CO₂). Moreover, the higher the concentration of carbon dioxide, the faster the algae will gain weight [3].

Algae biodiesel is the third generation of biofuels obtained by processing plant raw materials. Vegetable fat is extracted from algae, which will be used to produce biodiesel [4]. Algae are universal because they do not have a
true root system or leaves. They do not contain cellulose or lignin, which improves the process of converting raw materials into biofuels [5]. For greater clarity, we can show quantitative comparative characteristics of the fat content in terrestrial plants and their aquatic relatives. In the Table 1 an amount of liquid fuel obtained from different raw materials is presented.

Table 1

| Raw material               | Liquid fuel, L |
|----------------------------|----------------|
| Corn                       | 68.4           |
| Soy                        | 181.7          |
| Sunflower                  | 408.8          |
| Algae (natural conditions) | 700.3          |
| Algae (laboratory parameters) | 56 781.0      |

It is also equally important that algae require 99% less water in a closed system than other terrestrial crops. Due to the fact that aquatic plants do not have a strong stem and roots and accumulate nutrients over their entire surface, they are able to gain biomass much faster than other crops [6].

In the last 5 years, crop oil has become more expensive due to rising fertilizer prices, as well as their later transportation. Here again, algae are an alternative, as the production of algae oils using low-cost waste is a very attractive alternative to next-generation biofuels. Also, the use of seaweed oil, instead of that obtained from food crops, does not compete with food and does not affect food prices.

But, despite the great prospects of bioenergy from algae, their cultivation is also not a cheap pleasure. For example, if we take into account the heterotrophic cultivation of algae. Heterotrophic cultivation is based on the use of sugar as a carbon source and leads to a much higher oil content compared to those grown under phototrophic conditions. But this technology is expensive and competes with the food market, which complicates the economically successful application of the method.

We propose to consider in more detail the approaches to the implementation of this type of bioenergy. As is already known, there are certain varieties of algae that contain a significant amount of vegetable fats, from which in the future you can make the same biodiesel. It is not surprising that in order to obtain biofuels from algae, they need to be grown, but for this you do not need to occupy the sown area of the land fund. Lower plants can grow in ponds, on the seabed or in specially arranged bays, ie algae occupy those areas that are not involved in food production. That is why we can say that the third generation of biofuels is still in the development stages, but it is already clear that this bioenergy has the greatest prospects [7].

The main problems that arise during the cultivation of algae in open water is excessive sensitivity to temperature fluctuations. To overcome this problem, scientists have begun to practice the technology of growing algae in small bioreactors. Moreover, in bioreactors located near thermal or nuclear power plants. Thus, the waste heat of power plants will be able to cover up to 77% of the algae's heat needs. Thus, this technology will not require a hot desert climate, but on the contrary allows you to get biodiesel from algae in any part of the planet. Bioreactors can solve most of the problems faced by algae grown in open water. But on the other hand, bioreactors require significant financial investment [8].

Algae are unpretentious and easy to grow and feel good in mineral-poor environments. Their growth requires only the presence of sunlight, carbon dioxide and nitrogen, but the amount of nitrogen required is much less than that of algae for agricultural plants.

Among the approaches to the implementation of this type of bioenergy, there are two types of conditions:

1. Phototrophic conditions (presence of light and carbon dioxide as a carbon medium);
2. Heterotrophic conditions (lack of light, the presence of glucose as a carbon source and the presence of organic molecules as raw materials).

At the same time, phototrophic conditions will not only be cheaper, but will help solve greenhouse gas problems. Whereas heterotrophic conditions require significant investment, as sugar is a competitive product on the market [9].

**Research methodology**

The study was based on the analysis of theoretical studies and comparison of different types of terrestrial biofuels with microalgae and organic waste, at the economic, environmental and social levels with calculations.

**Results and discussion**

Let's start with history, countries such as Japan, Israel, France, the United States and Germany became interested in algae biofuels for the first time in the 1970s during the oil crisis. But as soon as the crisis receded, alternative energy from algae was forgotten. But the coming second wave of the disappearance of mineral energy reserves, forced to restore the energy of the 70's [10].

At this stage, Sustainable Green Technologies (SGT) is developing new technologies related to the extraction of oils and algae (Fig. 1). They focused on processes that will produce high amounts of biomass and on a steady increase in the percentage of algae oils.
So, while you do not have to pay for sunlight and it is more than enough for alternative energy, it compensates about 80% of the total for this technology. The rest of the amount falls on the conditions of growing algae [12].

Scientists from European countries have proven that the energy potential of algae is much more efficient than the potential of oilseeds (including rapeseed and sunflower). Thus, the energy potential of algae is 50–100 times greater than the potential of crops. In addition, algae grow 20 to 30 times faster than terrestrial plants and require only sunlight, temperature maintenance and carbon to grow. This is why the cost of growing algae is much lower than the cost of growing oilseeds, especially considering that bioreactors can be built near power plants, thus reducing the investment in finding heat to grow algae. Moreover, if bioreactors are installed near thermal power plants or nuclear power plants, it is possible to save society from CO2 emissions.

Thus, the development of algae bioenergy is cost-effective and investment-attractive, contributes to improving the environmental situation, increasing competitiveness and reducing the country's energy dependence [13]. Of course, the production of biofuels from algae has its drawbacks, but it should be noted that they are much smaller than in the production of terrestrial plants.

As for the shortcomings of algae bioenergy, researchers at Sustainable Green Technologies have previously faced the problem of low oil yields. But the company has successfully developed the Lipi Trigger method, which has helped to synthesize almost 3 times more oils without disrupting plant growth, so this problem has become a problem [14]. We propose to move on to more mathematical and specific characteristics that are listed in the following three tables.

**Economic block**

Now you can observe the economic performance of various terrestrial plants and algae (Table 2). The following plants were used for comparison: sunflower, corn, rapeseed, soybeans and algae. And among the characteristics: the cost of equipment, the duration of the growing cycle, yield, and fat content. Looking at this table, we can say that algae are in the lead in all respects, in other words, one characteristic complements another and makes up the whole picture of attractive indicators.

By comparison, we can say that these parameters of algae can not even be close to the parameters of terrestrial plants.

For example, take corn, the growing cycle would not seem large, even the lowest among terrestrial 6–25 days, but the fat content is not attractive, moreover, their rate is the lowest of all. Well, here I think everything is clear and algae occupy the honorable first place of the economic block.

**Table 2**

Comparative analysis of economic characteristics of biofuels [15]

| Plant   | Cost of equipment | The duration of the growing cycle | Crop capacity (2017–2020) | Fat content per 0.4ha |
|---------|-------------------|----------------------------------|---------------------------|----------------------|
| Sunflower | The price of equipment for sunflowers is higher than ordinary firewood | 6 – 8 weeks | 10.1 – 14.2 million tons | 408.8L |
| Corn     | The cost of plant equipment - $200 million | 6 – 25 days | 35.8 – 40.2 million tons | 68.4L |
| Rapeseed | 450 thousands of dollars | 45–55 days | 1.1-1.2 million tons | 480.7L |
| Soy      | 3 058 523.28 UAN | 95–110 days | 1.8 – 2 million tons | 181.7L |
| Algae    | 4300 dollars | 3–10 days | 500 million tons | Natural conditions – 7003L Lab. conditions – 18 927 – 56 781L |
Assessment of biofuel production from microalgae

The average annual productivity of microalgae growth in biomass, when cultivated in a photobioreactor in the weather conditions of Ukraine can be taken 11.5 kg/m² of the surface of the working area of the photobioreactor (culture medium) [16; 17]. The average lipid productivity will be 4.1 kg/m².

Provided that the wastewater is in the working area of the photobioreactor as a culture medium for an average of 3 days, the total volume of the working areas of photobioreactors for wastewater treatment of the urban population of Ukraine will be:

\[ 5.8 \times 10^9 \times 3 = 17.4 \times 10^9 \text{ l}, \text{ or } 17.4 \times 10^6 \text{ m}^3. \]

If the thickness of the effluent layer as a culture medium in the working area of the photobioreactor does not exceed 0.2 m, the total area of all photobioreactors should be

\[ \sum S_{\text{photobioreactor}} = \frac{17.7 \times 10^6}{0.2} = 87 \times 10^6 \text{ m}^2. \]

Thus, the annual increase in biomass of microalgae can be:

\[ M_{\text{biomass}} = 87 \times 10^6 \times 11.5 = 1000.5 \times 10^6 \text{ kg}. \]

The annual increase in lipids will be:

\[ M_{\text{lipid}} = 87 \times 10^6 \times 4.1 = 356.7 \times 10^6 \text{ kg}. \]

In real conditions, with the efficiency of removal of microalgae biomass from wastewater 90% (data for centrifugation), the efficiency of separation of lipids from biomass of microalgae 90 %, as well as energy efficiency of processing lipids into biofuels 90 % annual mass of biofuel (biodiesel)

\[ M_{\text{biofuel}} = 356.7 \times 10^6 \times 0.9 \times 0.9 \times 0.9 = \]

\[ = 260.0 \times 10^6 \text{ kg}. \]

Given that the density of biodiesel is 0.86 kg / l, the volume of biodiesel obtained will be:

\[ W_{\text{biofuel}} = \frac{260.0 \times 10^6}{0.86} = 302.4 \times 10^6 \text{ l}. \]

Assuming the price of one liter of biodiesel at UAH 28, the total annual profit from the sale of biodiesel will be:

\[ \Pi_{\text{biofuel}} = 302.4 \times 10^6 \times 28 = \]

\[ = 8466.2 \times 10^6 \text{ UAH}. \]

Assessment of biogas production from organic waste

Calculation of the biogas yield:

\[ V_{\text{biogas}} = m \times n, \]

where \( V_{\text{biogas}} \) — volume of the biogas income; \( m \) — mass of organic waste collecting during 1 year; \( n \) — amount of biogas generated from 1 tone of the organic waste. The 350 m³ of biogas generated from 1 tone of the organic waste.

\[ V_{\text{biogas}} = 11 731 516 \times 350 = 4 106 030 656 (\text{m}^3). \]

Calculation the volume of methane present in biogas:

\[ V_{\text{methane}} = \eta \times V_{\text{biogas}}, \]

where \( V_{\text{methane}} \) — volume of methane present in biogas; \( \eta \) — percentage of the methane content in biogas; \( V_{\text{biogas}} \) — volume of the biogas income.

The approximate percentage of methane content in biogas equals 80 %.

\[ V_{\text{methane}} = 0.8 \times 4 106 030 656 = 3 284 824 525 (\text{m}^3). \]

Calculation of the methane cost (income after 1 year of exploitation):

\[ C = V_{\text{methane}} \times b, \]

where \( C \) — the methane cost (UAH); \( b \) — 1 m³ methane cost.

The 1 cubic meter of methane cost 15.50 UAH.

\[ C = 3 284 824 525 \times 15.50 = 50 914 780 134 \text{ (UAH)}. \]

Calculation the cost of fertilizer from biogas reactors:

\[ C_a = \eta_t \times V_{\text{org}} \times f, \]

where \( C_a \) — cost of fertilizer from biogas reactors; \( \eta_t \) — the percentage of the dry fertilizer from amount of organic waste; \( f \) — the fertilizer cost from 1 m³.

The approximate percentage of the dry fertilizer from all amount of organic waste equals 25 %. This explained by drying of the organic fertilizers for further usage, from the one hand, and by the second usage of the residue as a substrate for new cycle in the reactor, on the other hand. The fertilizer cost from 1 m³ equals 250 UAH.

\[ C_a = 0.25 \times 83 796 544 \times 250 = 5 237 284 000 \text{ (UAH) [18]}. \]

Ecological block

Next we will analyze the ecological and at the same time the most interesting block for us (Table 3). The plants we have remained the same, and among the parameters: production area, chemical reagents and emissions into the atmosphere. As for the production area, everything is obvious, but algae can occupy minimal areas,
while giving a large amount of yield. In addition, algae do not require preparation and fertilization and are very easy to grow. As already mentioned, there are two types of conditions for growing algae: phototrophic conditions and heterotrophic conditions (lack of light, the presence of glucose as a carbon source and the presence of organic molecules as raw materials). And all of them are not only not expensive, but also environmentally friendly. According to the indicators of terrestrial plants, they all require the application of fertilizers, and accordingly create emissions into the atmosphere [19].

### Table 3

| Plant     | Production area (2018 – 2020) | Chemical reagents | Emissions into the atmosphere |
|-----------|--------------------------------|-------------------|------------------------------|
| Sunflower | 4000 – 7000 thousand hectares | Synthetic additives and chemical compounds are not used in the production. However, fertilizers are used during germination | No dangerous volatile substances or allergens are released during combustion. The volumes of carbon dioxide emitted are insignificant, so the atmosphere is not particularly damaged |
| Corn      | 4000 – 5000 thousand hectares | Requires significant application of mineral fertilizers and plant protection products | In general, the use of corn for energy purposes can reduce greenhouse gas emissions by 30% |
| Rapeseed  | 61.6 thousand hectares        | Rapeseed yields require more fertilizer than grain | Emissions of volatile organic compounds, in particular hexane, in interaction with nitrogen oxides cause the formation of photochemical smog, which adversely affects almost all components of ecosystems |
| Soy       | 112.5 thousand hectares       | When grown, it requires the application of fertilizers with micro- and microelements | Because soy require fertilization, it has a fairly significant percentage of greenhouse gas emissions and other harmful substances into the atmosphere |
| Algae     | 7500000 thousand hectares     | Growing algae does not require preparation and fertilization | Growing algae can help solve the problem of the greenhouse effect |

### Social block

So we moved on to the last, social block, which includes such parameters as: competition in the market, production in Ukraine and the scale of traditional fuel replacement (Table 4). The table is simple and everything is clear here. The only thing I want to say is that Ukraine is really capable of growing algae, because it has everything it needs, it is algae with a high fat content, which are grown in the Black Sea, Dnieper, and equipment for their processing, which is also produced in Ukraine. The whole table is identical, the only thing is that these algae do not compete in the Ukrainian market, which is convenient [16; 23; 24].

### Table 4

| Plant   | Competition in the market (+/–) | Production in Ukraine (+/–) | Traditional fuel replacement score (1–5) |
|---------|----------------------------------|----------------------------|------------------------------------------|
| Sunflowers | +                               | +                          | 5                                       |
| Corn    | +                                | +                          | 5                                       |
| Rapeseed | +                               | +                          | 5                                       |
| Soy     | +                                | +                          | 5                                       |
| Algae   | -                                | +                          | 5                                       |
Conclusions

Organic substance as microalgae have been experimented as a potential feedstock for biofuel generation in current era owing to its’ rich energy content, inflated growth rate, inexpensive culture approaches, the notable capacity of CO₂ fixation, and O₂ addition to the environment. Thus, the development of bioenergy from algae is cost-effective and investment-attractive, helps to improve the environmental situation, increase competitiveness and reduce energy dependence of the country. Currently, research is ongoing towards the advancement of microalgal-biofuel technologies.

The implementation of the technology of biofuel production from organic waste also warns of danger, first of all for people. By reducing free waste, use it as a secondary material and benefit from it. Integrated waste management technology includes successive steps that take into account the environmental, economic and social spheres of life. After analyzing the economic efficiency of the biogas reactor system, we can recommend one or another system to generate revenue from garbage collection.

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ОЦІНКА ТЕХНОЛОГІЙ ВИРОБНИЦТВА БІОПАЛИВА З МІКРОВОДОРОСТЕЙ ТА ОРГА- НІЧНИХ ВІДХОДІВ

Вступ. На сьогодні, переробка органічних речовин, таких як органічні відходи або мікророслини, є важливим способом отримання відновлюваних джерел енергії. Для підтримки процвітаючого життя населення надзвичайно важливо знайти відновлювані джерела енергії.

Постановка проблеми. В недалекому майбутньому мінеральні та органічні запаси земних надр переста- нуть задовольняти всесвітні енергетичні потреби цивілізації. Вже сьогодні з'являються технології, що дозволяють виробляти органічне паливо на основі відходів. Але вирощування таких культур призводить до виснаження земельних ресурсів. Іншими словами, верхній та нижній ряд гумусу поступово виснажується, що може вести до зниження міцності гектарів орних угідь. Тому заміну звичайних культур приходять мікророслини.

Методологія дослідження. Дослідження розглядали на аналіз теоретичних досліджень та порівняння різних типів біологічних палив з рослин земного типу та з мікророслини, на економічному, екологічному та соціальному рівнях.

Результати та обговорення. Біодизель з мікророслини — паливо третього покоління, яке отримують шляхом переробки рослиної сировини. Як відомо, водорості характеризуються високим вмістом жирних кислот, які є основою для виробництва біодизелю. Мікророслини дуже дешеві і, одночасно, — високопродуктив- них. З одного гектара мікророслини виробляють біолій, ніж з гектару сої. При цьому значно зернів рослиноміці, ніж біодизель з рослинних олій. Крім того, мікророслини гораздо дешевіше, ніж рівні фітосировини. Наприклад, водорості, що на 80% складаються з речовин, аналогічні рослин, зуміли виростати за 10 днів, тоді як ті ж самі водорості, що на 30% складаються з речовин асоціації, виростають лише за три дні. Ще одним плосом використання мікророслини можна вважати той факт, що на відміну від вирощування інших видів рослинної сировини, їх неабсолютне необходи- мості підходів і удобрівання — для зростання вони використовують вуглець та газ (CO2). При цьому вони приносять більш високий прибуток.

Висновок. Органічна речовина у вигляді мікророслини експериментується як потенційна сировина для виробництва біодизеля в поточну епоху здійснити кількісному енергетичному вісю, підвищений швидкість росту, недорогим відходам до вирощування, поліпшений енергетичні фіксації CO2 і підданням O2 в навколишнє середовище. Впровадження технології виробництва біодизеля отримає органичних відходів також попереджає про небезпеки, передні для людей. Зменшуючи відходи, використання їх як вторинний матеріал і отри- мання від цього користь. Інтегровані технології вирощування з відходами включає послідовні кроки, які врахо- вують екологічну, економічну та соціальну сферу життя.

Ключові слова: мікророслини; органічні відходи; біопаливо; екологічна безпека; сталий розвиток.
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ASSESSMENT OF BIOFUEL PRODUCTION TECHNOLOGIES FROM MICROALGAE AND ORGANIC WASTE

Introduction. Today, the processing of organic matter, such as organic waste or microalgae, is an important way to renewable energy sources. To maintain a prosperous life of the population, it is critical that renewable sources of energy be found.

Problem statement. In the near future, mineral and organic reserves of the earth's interior will cease to meet the growing energy needs of civilization. Already today, technologies have emerged that allow the production of fossil fuels based on many plant species. But the cultivation of such crops leads to depletion of land resources. In other words, the top and thin fertile layer of humus is gradually depleted, which can lead to the use of millions or billions of hectares of arable land. And here to replace usual terrestrial cultures come microalgae.

Research methodology. The study was based on the analysis of theoretical studies and comparison of different types of biological fuels from plant-type and microalgae, at the economic, environmental and social levels.

Results and discussion. Biodiesel from microalgae is a third generation fuel obtained by processing vegetable raw materials. It is known that algae are characterized by a high content of fatty acids, which are the basis for the production of biodiesel. Microalgae are very cheap and, at the same time — highly productive raw materials. One hectare of microalgae produces 30 times more biofuel than one hectare of soybeans. At the same time, biofuel from algae is 5-10% more energy-intensive than biodiesel from vegetable oils. In addition, microalgae grow quite rapidly. For example, algae, which is 80% composed of substances similar in origin to oil, grows in 10 days, while the same algae, which is 30% composed of substances similar in origin to oil, grows in only 3 days. Another advantage of using algae is the fact that, unlike growing other types of plant materials, they do not need to be fed and fertilized — they use carbon dioxide (CO₂) for growth. The higher the concentration of carbon dioxide, the faster they are cultivated. Thus, the cultivation of microalgae can solve several problems: the problem of the greenhouse effect; the problem of employment of sown areas; the problem of shortages of traditional fuels and many other equally important problems.

Conclusion. Organic substance as microalgae have been experimented as a potential feedstock for biofuel generation in current era owing to its' rich energy content, inflated growth rate, inexpensive culture approaches, the notable capacity of CO2 fixation, and O2 addition to the environment. The implementation of the technology of biofuel production from organic waste also warns of danger, first of all for people. By reducing free waste, use it as a secondary material and benefit from it. Integrated waste management technology includes successive steps that take into account the environmental, economic and social spheres of life.

Keywords: microalgae; organic waste: biofuel; environmental safety; sustainable development.