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Biofuels as a challenge of sustainable development

ABSTRACT

Bioenergy, or energy derived from biomass, today is recognized as an important component in many energy scenarios, being an integral part of various global, regional, and national policies and strategies. This has led to intensified research into more efficient biofuel production. This paper explains the advantages, disadvantages, and problems related to the production of biofuels from different types of raw materials. Several examples of commercialized and demonstration plants for the production of biofuels in different parts of the world are listed. It is to be expected that, with greater use of modern biofuel production solutions, the contribution of these sources of (bio)energy will be the main part of future energy consumption from renewable sources.

Keywords: *biofuels, biomass, bioenergy, sustainability, energy policy.*

1. INTRODUCTION

It is a well-known fact that today the transport sector is almost completely dependent on fossil fuels (gasoline, diesel, liquid petroleum gas, kerosene). Considering that, the demand for those fossil fuels is growing every day. Taking into account this fact, and the fact that the supply of crude oil is decreasing, in already known deposits, it was necessary to find an alternative solution, that is, to develop existing or new alternative technologies for the production of transport fuels, i.e., fuels that could replace current commercial fuels. During the "energy crisis" of the 1970s, there was a global shortage of energy sources. This crisis encouraged politicians to direct financial resources and support the scientific community in initiating research and technological development in the field of biofuel production, i.e. fuel produced from biomass [1]. At the same time, the emergence of modern environmental issues (global warming, REACH legislation, etc.), as well as the global agreement on sustainable development, have encouraged research institutes and industries to work on the development of alternatives to petroleum products [2-5].

It is possible to transform the chemical energy of biomass into various forms of secondary energy, i.e., into gaseous or liquid biofuels. In general, biomass conversion technologies can be principally divided into 3 groups [6-9]:

- Thermochemical conversions (carbonization, gasification, pyrolysis),
- Physicochemical conversions (transesterification, pressing, extraction, etc.),
- Biochemical conversions (alcoholic fermentation, enzymatic hydrolysis, anaerobic fermentation, etc.).

Liquid and gaseous fuels obtained by thermochemical processes are called synthetic biofuels. Within the scope of thermochemical conversions, the production of synthetic gas (syngas) by gasification of biomass stands out. Synthesis gas is primarily a mixture of carbon monoxide and hydrogen, but it also contains smaller amounts of carbon dioxide, methane, water, and other side products, as well as nitrogen, which depends on the conditions of the process, the type of raw material, and the performance of the gasification system. Although syngas can be used as a stand-alone fuel, its energy density is approximately half that of natural gas. Therefore, synthesis gas is mainly used as an intermediate block of molecules, for the production of transportation fuels and other chemical products [10-14]. Some of the applications include the production of:

- hydrogen in refineries;
- diesel fuel, using the Fischer-Tropsch synthesis;

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- artificial fertilizers, using ammonia obtained from syngas and nitrogen;
- methanol, by catalytic hydrogenation;
- dimethyl ether, by catalytic hydrogenation;
- synthetic natural gas, methane;
- electricity, by burning synthesis gas.

Regarding the production of synthetic biofuels, today a special focus is placed on biomass pyrolysis technologies [15,16]. The advantage of pyrolysis compared to other thermal processes is the simultaneous obtaining of a wider range of important products (bio-oil, carbonized residue, and gas), while emissions of pollutants are significantly lower. Studies of these processes are carried out under different experimental conditions, in different types of reactors, and with different raw materials [17-20].

In general, these processes are still in the development phase and whose products (biofuels) are not competitive in price with products obtained by processing fossil raw materials, so mass industrial production of synthetic biofuels has not yet taken off [21,22]. Nevertheless, there are numerous examples of both demonstration and commercialized plants for the production of synthetic biofuels, which is a consequence of increasing political pressure and certain international obligations regarding the increase in the use of renewable energy sources [23-32].

2. DEFINITION, CLASSIFICATION, AND IMPORTANCE OF BIOFUELS

Fuels produced directly or indirectly from biomass are called biofuels [33]. Therefore, it is about any fuel that can be obtained from biomass. In general, biofuels can be in all three aggregate states, although today special preference is given to the production of liquid biofuels, considering that they serve as a substitute for the most common conventional fuels - diesel, gasoline, and kerosene.

Biofuels are usually classified into primary and secondary biofuels. Primary biofuels include unprocessed biomass, i.e., biomass that is processed exclusively by mechanical technologies, such as firewood, wood chips, briquettes, or pellets, while secondary biofuels refer to fuels obtained by processing biomass, such as e.g. bioethanol, biodiesel, dimethyl ether, etc. [34]. Biofuels can also be classified into "generations", based on the type and origin of the biomass from which they are produced, namely first, second and third-generation biofuels [6,34].

- **First-generation biofuels** - fuels obtained from edible crops such as, for example, oilseeds or other carbohydrate-rich biomass, or from other edible raw materials such as food scraps. Large quantities of first-generation bioethanol are produced in the USA, mostly from corn, and in Brazil from sugar cane [35]. For example, about 34 million and 25 million liters of this fuel were produced in the USA in 2009, while the total world production of bioethanol that year was about 66 million liters [36]. The most important biofuels of the first generation are bioethanol, biodiesel, and biogas. These biofuels are obtained by relatively simple processes. These are predominantly biochemical processes in the production of bioethanol, transesterification processes in the production of biodiesel, and anaerobic digestion processes in the production of biogas.
- **Second-generation biofuels** - fuels that are obtained from the inedible part of crops (e.g. husks, ears of corn, cornstalk, straw, pruning residues), inedible biomass in general (e.g. different types of grass, waste), or from specially grown tree crops, inedible oilseeds, and others called energy crops. Biochemical and thermochemical processes, or their combination, are used to obtain these biofuels. These include fuels such as cellulosic bioethanol, bio-methanol, isobutanol, synthetic methane, pyrolytic oils, synthetic gas (syngas), Fischer-Tropsch fuels, biohydrogen, etc.
- **Third-generation biofuels** – the last generation of biofuels originating from microbes and microalgae. An integrated system of biofuel production from microalgae includes appropriate cultivation, harvesting, drying, and extraction of lipids for the production of biodiesel through the transesterification process, as well as enzymatic hydrolysis to obtain fermentable sugars that are distilled into bioethanol using conventional technologies [37-39]. Some authors also include biofuels whose production is based on certain biotechnological interventions on the raw material itself as third-generation biofuels [6]. Plants are grown in such a way that the building blocks of their cells (lignin, cellulose, hemicellulose) can be manipulated, but according to the specific requirements of their further processing technology. For example, trees are grown in a normal way until a certain moment when a change in the structure of the cell walls is initiated, which allows them to tear more easily and release sugar more easily.

The basic problem with first-generation biofuels is that as their production increases, so does the need for arable land, which is or would otherwise be used for food production [40]. This leads to loss of biodiversity, excessive water use, and increased greenhouse gas emissions. We should also not ignore the decrease in food production at the expense of the increase in biofuel production, and the consequent increase in food prices [41]. Already, the International Energy Agency (IAE) predicts that by 2050, 100 million hectares will be needed to supply 27% of transportation fuels, which corresponds to approximately 6% of arable land, which according to UN projections will be available by 2050 [42, 43].

The advantage of second-generation biofuels compared to first-generation biofuels is reflected in the fact that the mentioned problem of competitiveness of food production and biofuels is avoided, by the very fact that edible raw materials are not used. Also, the raw materials for second-generation biofuels can be produced by dedicated, different energy crops, which enables higher production per unit of land area, thus increasing the efficiency of land use compared to first-generation biofuels. Moreover, second-generation biofuels are believed to have the potential for lower production costs and the production of significant amounts of energy, with several environmental benefits. However, it is necessary to emphasize the shortcomings of second-generation biofuel production. For example, the production of inedible oils from plants such as *Jatropha curcas, Pongamia pinnata, Simarouba glauca*, etc. or lignocellulosic biomass uses vast areas of agricultural land that could otherwise be used for food production [41]. Also, the raw material itself is more complex compared to raw materials for first-generation biofuels, so more sophisticated and complex equipment is needed for processing and production [34]. A special problem is the extraction of useful sugars from lignin and cellulose, and the need for appropriate enzymes to release sugar molecules from cellulose. Enzymatic hydrolysis required to convert lignocellulose to ethanol is an expensive process and also a technical challenge [41]. Therefore, a lot of work and research is still needed to make this fuel economically viable, e.g., cellulosic ethanol currently costs two to three times more than an energy equivalent amount of fossil fuel [44].

Biofuels of the third generation, i.e., biodiesel and biohydrogen obtained from algae, today represent a widely accepted and promising alternative source of energy, the production of which eliminates the negative effects of the production of biofuels of the first and second generation [38, 45-48]. Namely, these organisms (algae) can use different sources of water and can be grown on neglected and barren lands, meaning without depriving the land of food production [41]. Microalgae can produce 15 to 300 times more oil for biodiesel production per unit area than traditional crops, i.e., oilseeds [34]. Traditional crops are cultivated once or twice a year, while microalgae have a very short harvest period of only 10 to 30 days, which significantly increases the total yield of biofuel obtained from algae [49]. It can be said that algae have a much higher potential for converting (fixing) carbon dioxide from the atmosphere into useful biomass, through the process of photosynthesis, compared to traditional biomass [50]. For example, the average carbon dioxide fixation potential of forest biomass and algae is 1.78 kg/kg/year and 1.6 - 2 kg/kg/year, respectively, while the yield of this biomass per unit area is 2.6 - 3.9 t /ha/year in the case of forest biomass, and in the case of algae, it is 127 - 250 t/ha/year [51]. In general, it is considered that the production of these biofuels is commercially profitable, because the price of their production is competitive with the production of fossil fuels production, there is no need for additional agricultural land, it uses minimal water, and improves air quality due to the absorption of carbon dioxide from the atmosphere. Today, there is already talk about fourth-generation biofuels, which refer to the use of genetically modified algae that have higher biofuel production [52-54].

Third and fourth-generation biofuels are considered to be the main sources of biodiesel in the near future [55]. According to IEA forecasts, by 2035 these advanced types of biofuels will account for 20% of the total global biofuel production. A few key predictions involving renewable energy, made by the IEA, are [53]:

- Global energy demand will increase by more than 66% from 2011 to 2035, with the bulk of the increase coming from non-OECD countries;
- Biofuel use will triple from 1.3 million barrels of oil equivalent in 2011 to 4.1 million barrels of oil equivalent in 2035;
- Subsidy costs for biofuels will continue to increase due to the strong growth in their use.

These predictions represent a positive outlook for biomass and should spur interest in research and investment in the biomass and biofuel supply chain. Despite the potential risks discussed above, biomass has a solid future as a competitor to fossil resources. However, mass production of biofuels that would have a significant impact on overall production and energy requirements is still a demanding task [34].

3. OVERVIEW OF GLOBAL AND NATIONAL BIOFUEL POLICIES

There is a large number of different regional, national, and international policies and appropriate instruments that promote the use of biomass in energy production, the so-called bioenergy. In general, it is possible to make some distinctions between international/global and national or regional policies in this area, although they overlap in some parts [56].

As for global policies, they refer to those policies, or rather agreements, which have been adopted by international organizations. The United Nations Framework Convention on Climate Change (UNFCCC), especially its part related to Climate Change Mitigation (COP) and Reducing Emissions from Deforestation and Forest Degradation (REDD), stands out here. This also includes certain global trade relations defined by the World Trade Organization (WTO). Within the framework of global policies, the various established global methodologies for sustainability certification, as well as those that are in the development phase, are particularly noteworthy. Examples: EU Organic Farming, FSC (Forest Stewardship Council), GGL (Green Gold Label), SAN (Sustainable Agriculture Network), LEED (Leadership in Energy and Environmental Design), etc. [57-59].

National and regional policies regarding the energy utilization of biomass are defined by individual states or their communities, e.g., European Union (EU). These include policies, i.e., different legislation, strategies, or action plans, which regulate different uses of biomass. For example, the use of biofuels in the transport sector, in the sector of electricity production, thermal energy, etc. This also includes various national or regional sustainability criteria and corresponding certifications. A significant number of countries has developed or are developing their biomass sustainability criteria, especially regarding biofuel production. There are also national and bilateral trade relations. For example, in OECD (Organization for Economic Co-operation and Development) member countries, existing trade policies have a strong impact on the price and potential of biomass use at the national level. The potential of using (relatively) cheap biomass is increased by removing barriers to the import of biomass. In many countries, there are also various programs of financial and other support for development and research to improve the efficiency, economy, and sustainability of various biomass applications. Perhaps the most famous example of this is the EU support programs for the development of second-generation biofuels, e.g. cellulosic bioethanol, FT diesel, and DME.

As for the EU, it can be said that it strongly supports the sector of using biofuels, especially in the last ten years, which is reflected in the so-called EU Energy and Climate Change Package, i.e., a set of laws that ensure the fulfillment of certain energy and climate goals by 2020:

- Reduction of greenhouse gas emissions by 20% compared to the base year of 1990;
- Increase in energy efficiency by 20% and
- 20% share of renewable energy in total energy consumption.

The stated general goals are supported through two EU directives, which focus in particular on the transport sector. The first is the Fuel Quality Directive, which requires member states to reduce the intensity of greenhouse gas emissions from fuel by 6% in 2020 compared to 2010 [60]. The second is the Renewable Energy Directive (RED), which requires that at least 10% of transport fuels in each member state come from renewable sources by 2020, with biofuels also having to meet certain sustainability criteria [33]. These criteria include reducing greenhouse gas emissions by 35% compared to fossil fuels, as well as avoiding growing raw materials (biomass) on land with rich biodiversity or land with high carbon stocks. To deal with the problems of indirect land use change, since 2012 the EU Commission has been promoting the transition from first to second-generation biofuels by attaching a certain weighting factor to second and third-generation biofuels. Namely, second-generation biofuels produced from lignocellulosic biomass, waste, inedible cellulosic matter, or cellulosic residues are counted twice in achieving the goals defined by the RED Directive. Biofuels produced from municipal and industrial waste, straw, algae, palm oil, leaves, sawdust, and twigs count four times in achieving the goals defined by the RED Directive. According to the latest processed and official data of the EU Commission, the EU is well on its way to meeting the stated goals. For example, it is stated that the share of energy from renewable sources in total energy consumption has already reached a value of 18% (18.9% for the EU27) in 2018, thus confirming the achievement of the goals in 2020 [61].

In general, it can be said that the current policies in the biofuels sector in the EU, but also in the USA, have become the driving force for the development of second-generation biofuels at the global level. The use of biofuels has increased in many regions around the world. On an annual level, approximately 30 billion liters of biofuel are currently consumed in Europe and North and South America [62].

In the main case, global demand for biofuels over 2021-2026 is set to grow by 28% (41 billion liters) and Asian biofuel production is expected to be larger than one in Europe during the forecast period due to its strong domestic policies, growing liquid fuel demand and export-driven production [63]. Regarding policy environment, oil prices, and the fact that biofuels compete with food use and may have undesired land use effects, countries are cautious about expanding biofuel production at a faster pace. Yet, the biofuel production and the biodiesel market expanded, due to higher blending requirements, tax credits, direct subsidies, and decarbonization initiatives in the market. Demand for biofuels is expected to increase due to developments in transportation fleets, domestic policies that favor higher blends, and greater demand from consumers. It is expected that this amount will increase significantly, due to the growth in demand for transportation biofuels. By 2031, global ethanol production is projected to increase to 140 billion liters, and biodiesel to 55 billion liters, primarily, as already mentioned, due to expansion in Asian countries. Currently, only in Brazil, the share of energy entering the transportation sector through biofuels exceeds 10%. Although the USA should remain the world's largest ethanol producer, its global production share is projected to decrease from 47% to 44%. Likewise, a decrease in biodiesel production of 1.4% per year is predicted, so that in 2031 it would account for 16% of global production. By 2031, the EU will remain the world's largest region for biodiesel production, although the global share of production is expected to drop from 30.7% to 28%. Total biofuel consumption in the EU is projected to decrease by 1.5% per year, but the share of advanced biofuel sources (cellulosic ethanol or hydrogenated vegetable oil - HVO) should increase from 24% currently to 37% by 2031 [64].

4. BIOFUEL PRODUCTION CASE STUDIES

In this section, several examples of commercialized and demonstration plants for the production of various synthetic biofuels are given. All the listed facilities (case studies) are of recent date and represent examples based on which new facilities are being developed, in response to the growing obligations regarding the fulfillment of the goals of a certain share of biofuel consumption in the total energy consumption.

A large part of the current pyrolysis capacity relates to the recycling of wood, forestry, and plastic waste. It is estimated that hundreds of plastic pyrolysis projects are underway worldwide, mainly in the US and Europe (Spain, the Netherlands, Great Britain, and Germany). Pyrolysis technology for processing plastic, wood, and forest waste is gaining momentum in South Korea and Japan. Major end users of pyrolytic oil include oil giants such as Shell, ExxonMobil, and Chevron Philips, advanced players in biofuel production technologies such as Neste and Honeywell UOP, as well as chemical and plastics manufacturers such as INEOS, BASF, SABIC, and Toyo Styrene. Key technology performers in this area are Ensyn, BTG Bioliquids (BTG-BTL), Plastic Energy, Agilyx, Quantafuel, and Klean Industries [65].

Currently, several Canadian companies are using the fast pyrolysis process to produce bio-oil. **Ensyn Technologies**, founded in 1984, has designed and built seven pyrolysis plants in North America. The largest plant is located in Renfrew, Ontario, and processes about 100 tons of dry woody biomass per day [66].

The use of biofuels as a replacement for petroleum diesel is a valuable solution to the inevitable global issues related to energy shortages and environmental pollution. For economic and ecological reasons, biofuel production from used cooking oil (UCO) has gained significant attention [23]. The company **SeQuential** from the USA is one of those engaged in the production of biodiesel from waste cooking oil. SeQuential is the longest-running commercial biodiesel producer on the US coast. They collect used cooking oil from across the region and convert it into biodiesel - a cleaner, non-toxic diesel fuel that offers a 50% reduction in harmful particulates and hydrocarbon emissions and has up to 85% less carbon residue than petroleum diesel. Oil collected from the Northwest partners is taken to a production facility in Salem, Oregon, while oil collected in California is taken to a facility in Bakersfield. The capacity of the plant is 17 million gallons, or about 64 million liters of biodiesel per year [24]. **Tri-State Biodiesel** is a US company that also produces biodiesel from waste cooking oil. Tri-State Biodiesel collects material from 3,500 restaurants in New Jersey, Connecticut, and New York. The oil is then subjected to filtration to remove impurities, food residues, and water. After the raw material is purified, it is transported to the biodiesel production plant, where the transesterification reaction occurs with the addition of methanol, sodium methylate, and heat. Monoalkyl esters are formed by the transesterification reaction, i.e., biodiesel with glycerin as a primary co-product [25].

The company **BioMCN** is one of the largest European methanol producers and is the first factory in the world that produces and sells industrial quantities of high-quality biomethanol, a second-generation biofuel. In 2017, BioMCN produced almost 60,000 tons of biomethanol, which was primarily sold as biofuel in the European transport sector. In response to concerns about global climate change, the Netherlands has imposed stricter environmental regulations on carbon emissions and actively promoted the use of anaerobic digestion plants to process organic waste into biogas. As the availability of biogas increases in the future, BioMCN expects its biomethanol production to increase and its dependence on conventional natural gas to decrease [31].

Enerkem is a Montreal, Canada-based company that produces clean transportation fuels and renewable chemicals from feedstocks such as wood and agricultural biomass, and municipal solid waste. The company was founded in 2000 with the aim of further development and contribution to the economy. Their largest commercial-scale biofuel production facility is located in Alberta, Canada, helping the City of Edmonton increase its waste diversion goal from 50% to 90%. The company started biomethanol production in 2015. The capacity of the plant is 38 million liters of biofuel per year. The facility is designed to process over 100,000 tons of non-returnable waste per year that is otherwise destined for landfill [31].

The **BioTfueL** project launched by TotalEnergies from France and five partners is designed to convert lignocellulosic biomass (straw, forest waste, dedicated energy crops) into biofuel through thermochemical conversion. The goal is to develop a complete set of processes for the production of second-generation biodiesel and bio-jet fuel. The BioTfueL® technology, whose demonstration units for torrefaction are located in Venette and for syngas and Fischer-Tropsch (FT) fuel in Dunkirk (both in the Hauts-de-France region, France), is built on four key steps of industrial processes: torrefaction of biomass, gasification, treatment, and purification of the produced synthesis gas and subsequent conversion into advanced biofuels using the Fischer-Tropsch synthesis. The resulting biofuel, which will not contain sulfur and aromatics, will be usable in pure or combined form in all types of diesel and turbojet engines [27].

In Joensuu, Finland, there is a combined heat and power (CHP) plant for district heating, which uses wood and peat as raw materials. It is the first combined plant in the world that integrates the production of bio-oil. The heat for pyrolysis is transferred via hot sand from the fluidized bed of the boiler, while pyrolysis by-products, char, and waste gases are used as fuel in the boiler (in addition to peat and biomass). Using pyrolysis by-products as fuel to replace boiler fuel improves the overall energy efficiency of the process. The integrated CHP plant in Joensuu is producing heat, electricity, and 50,000 tons of bio-oil as a maximum planned capacity per year. The plant began full operation in 2015 [32].

The Ortofta CHP plant is connected to the district heating network in southern Sweden, which is operated by the energy company Kraftringen Energi AB. The district heating network delivered 3800 TJ of heat in 2018, and the plant works only during 2/3 of the year when there is an objective need to supply heat to the district heating (DH) network (5,300 hours/year). A study is currently being done to evaluate the potential integration of bio-oil production as a complement to the existing production of electricity and district heating. The produced bio-oil could be used internally during peak loads in the district heating network or sold to generate income. For bio-oil boilers currently used in cases of peak load in the DH network (operating when the outside temperature is below 0 °C) about 200 TJ/year of bio-oil is needed [26].

5. CONCLUSION

Biomass has been the most important source of energy (bioenergy) since the discovery of fire, and today it is the main source of energy for almost half of the world's population. In the past, the use of biomass as a biofuel was mostly limited to wood biomass, but today it has been significantly expanded to other sources of biomass, from various residues from agriculture and the food industry to dedicated agricultural crops, i.e. energy crops. It is expected that in the future the production of biofuels will significantly expand to the use of aquatic biomass, primarily microalgae, and seaweed.

Today, bioenergy - energy obtained from biomass, is recognized as an important component in many future energy scenarios and is an integral part of various global, regional, and national policies and strategies. Although there is an increasing demand for energy from fossil sources, due to the growth of economic activity in developing markets, especially in China and India, the constant rise in the price of oil has encouraged large consumers around the world to sharply increase the use of biofuels. This led to intensified research into more efficient production of biofuels, such as DME, biomethanol, and bioethanol, but also research into new processes and technologies, production of biofuels, such as solar thermochemical hydrogen or hydrogen from microbiological processes.

It is to be expected that, with greater use of modern biofuel production solutions, the contribution of these sources of (bio)energy will be the main part of future energy consumption from renewable sources.

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IZVOD

BIOGORIVA KAO IZAZOV ODRŽIVOG RAZVOJA

Bioenergija, ili energija dobijena iz biomase, danas je prepoznata kao važna komponenta u mnogim energetskim scenarijima, kao sastavni dio različitih globalnih, regionalnih i nacionalnih politika i strategija. To je dovelo do intenziviranja istraživanja efikasnije proizvodnje biogoriva. U ovom radu se objašnjavaju prednosti, nedostaci i problemi vezani za proizvodnju biogoriva iz različitih vrsta sirovina. Navedeno je nekoliko primjera komercijaliziranih i demonstracionih postrojenja za proizvodnju biogoriva u različitim dijelovima svijeta. Za očekivati je da će, uz veću upotrebu savremenih rješenja za proizvodnju biogoriva, doprinos ovih izvora (bio)energije biti glavni dio buduće potrošnje energije iz obnovljivih izvora.

***Ključne riječi**: biogoriva, biomasa, bioenergija, održivost, energetska politika.*

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