POLITYKA ENERGETYCZNA – ENERGY POLICY JOURNAL

2023 ✦ Volume 26 ✦ Issue 1 ✦ 77–92

DOI: 10.33223/epj/161810

Piotr Jan Plata[1], Agnieszka Nowaczek[2]

The BioRen project in the context of the development of new generations of biofuels

Abstract: In these times of the climate crisis surrounding us, the improvement of technologies responsible for the emission of the largest amounts of greenhouse gases is necessary and increasingly required by top-down regulations. As the sector responsible to a large extent for global logistics and supply chains, the fuel sector is one of the most studied in terms of reducing its harmful impact. The development of the next generations of fuels and biofuels, produced by companies using increasingly modern, cleaner and sustainable technologies, is able to significantly reduce the amount of greenhouse gases released into the atmosphere. In this case, the most effective solution seems to be the use of closed loops. Due to their low, often zero emission balance and the possibility of using waste to produce materials that can be reused, a circular economy is used in many sectors of the economy, while ensuring the emission purity of technological processes. One of the innovative solutions proposed in recent years is the installation created as part of the BioRen project, implemented under the Horizon 2020 program. The cooperation of European institutes with companies from the SME sector has resulted in the creation of an experimental cycle of modern technologies for the production of second-generation biofuels. The project involves the processing of municipal solid waste into second-generation drop-in biofuels. The entire process scheme assumes, in addition to

✉ Corresponding Author: Piotr Jan Plata; e-mail: piotr.jan.plata@gmail.com

[1] Chemistry Department, Warsaw University of Technology, Warsaw, Poland; ORCID iD: 0000-0003-1550-8619; e-mail: piotr.jan.plata@gmail.com

[2] Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Kraków, Poland; ORCID iD: 0000-0002-9920-9511; e-mail: anowaczek@min-pan.krakow.pl

the production of biofuels, the processing of inorganic fractions, the production of carbon material for the production of thermal energy, and the simultaneous treatment of wastewater.

KEYWORDS: waste management, energy, biofuel, circular economy, BioRen

Introduction

Climate changes occurring around the world, as a global problem caused by human activity, force many sectors of the global economy to modify the sources of energy acquisition, its use, technology and the whole logistics chains of its supply and production. Actions improving the quality and cleanliness of technology must first and foremost develop energy sectors such as refineries, power plants or entities related to the fuel industry or technologies related to transport and engine production. They are responsible for most of the global CO_2 emissions. A good example of this is transport sector, which in 2020 was responsible for 7.3 billion metric tons of carbon-dioxide emissions (Breakdwon of CO_2... 2021). This represents around 15% of the global economy's CO_2 emissions, at the same time, it ranks third in terms of the amount of energy consumption and greenhouse-gas emissions. This level is expected to increase by 60% by 2030 (BioEnergy 2023).

Production, transport and logistics technologies must be modernized as well as all those which, after production, ensure the operation and reliability of products. In the context of the transportation sector and making the global economy more and more motorized, engines and fuels become such entities. For years, manufacturers have been competing by making their technologies and better and better in order to optimize prices, the economy, efficiency and cleanliness at the best possible level. It is, of course, inextricably linked with the desire to be a pioneer of a given technology and production of the best available product on the market.

Engines, however, are not an exception in this regard. Fuels, as a permanent source of energy for the engine, should also meet modern standards, norms and guidelines. Whole process of their production should involve improving efficiency and limiting harmful emissions at the same time. Moreover, the process itself ought to be seen as integral in the sense of producing engines, which consume it. The development of the market and technologies of producing different types of fuels seems to be a necessity due to, as experts keep repeating, the lack of possibilities for the electrification of the entire transport and automotive sector, and even more so, of specialized technological machines. Electric cars, assuming that in the near future new battery disposal technology will appear, will surely play an important role in the global economy. It is, however, hard to imagine that big ships, long-distance planes or land forms of international transport could be fully electrified. It is also dangerous to rely on only one technology, especially at such an early stage in its worldwide implementation.

As a consequence of the above issues with electrification, fuels and their new forms and properties should still be considered and their development cannot be relegated to the background in favor of the development of battery technology. Simultaneously, with the development of production methods and plants, funds and time should be devoted to the development of scientific research. Scientific units dealing with the properties of substrates, production techniques and analyses or fuel material compositions must be involved in big consortiums. These kinds of actions will result in making exact definitions, parameters of properties and destinations of materials used in fuel production processes. Additionally, such a combination will result in increased security. The scientific side can more accurately analyze the impact of activities undertaken by through concern about the environment. The climate crisis is such an advanced and complex problem, that the elimination of one factor in an ill-considered manner may result in a build-up or accumulation of other new ones. This fact, instead of making the situation easier to resolve, can only complicate it.

Increasingly often, however, the discussion is being undertaken and developed as to whether the further development of conventional fuel technologies such as ethylene or diesel makes sense, especially in the context of ecology.

For many years, ecological technologies for the production of biofuels as a substance produced from the broadly understood biomass have been developed as the material which is willing to take over conventional fuels' place on market. The definition of biomass as a substrate for biofuel production is not obvious, but based on the EU directive, biomass is the biodegradable part of products, waste or residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, including fisheries and aquaculture, as well as the biodegradable part of industrial and municipal waste (Bhuiya et al. 2016a).

On the promotion of the use of energy from renewable sources, it is a freely available material and can even be assumed to be an inexhaustible and fully renewable source of energy (Rostek 2011). From biomass, it is possible to produce already known biofuels such as biodiesel or bio-ETBE (ethyl tert-butyl ether) but also fuels of the II, III or even IV generation and modern types of drop-in-type fuels. The latter are a group of fuels added to conventional fuels or biofuels to increase engine efficiency while reducing harmful emissions.

Biofuels, as substances produced from biomass materials, have a very low emission balance (Kargbo et al. 2021) but are also not so energy efficient. This fact makes it unlikely that they can one hundred percent replace conventional fuels and take over the entire fuel market. The aforementioned drop-in biofuels seem to be an opportunity in this case and context. Their addition to conventional fuels results not only in capturing, neutralizing or changing the physico-chemical properties of harmful substances emitted during combustion in the engine compartment. These kinds of biofuels also significantly affect the improvement of the engine's work culture, its economy and they indirectly improve the engine performance by increasing the octane number (Chiriboga et al. 2020).

The best example of that kind of closed cycle is a BioRen project, realized by tech and scientific entities from Belgium, Netherlands, Poland, Sweden and Spain. The project is being subsidized with HORIZON 2020 program funds and it assumes patenting biomass material transformation into II generation biofuel cycle. This material, in the BioRen project, comes from a solid fraction of municipal waste. The main assumption made by theBioRen consortium is that the biofuel production process should go hand in hand with the formation of biochar. For this purpose, hydrothermal carbonization technology HTC is being used. This carbon material, besides being an energy-giving material, can be used for carbon sequestration in soil, its fertilization and the remediation of sterile areas (Directive of... 2018).

1. I, II and III generation biofuels

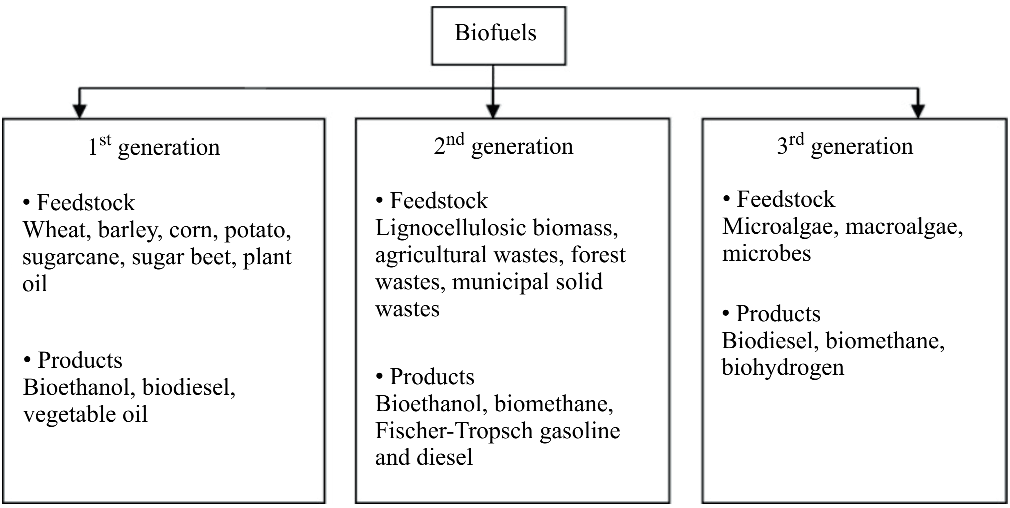

Fig. 1. Classication of biofuel production: the three generations of biofuels (Bhuiya et al. 2016b)

Rys. 1. Klasyfikacja produkcji biopaliw na przykładzie trzech generacji

Plant biomass is a material rich in solar energy, absorbed in the form of solar radiation by living plants during the process of photosynthesis (Jakóbiec and Wolszczak 2010). The transformation of such biomass on the principles of fermentation, combustion or gasification enables the obtaining of heat, electricity or energy raw material, which is fuel. The entire sector of biofuels is a very important direction in the development of the energy market, for example, because of the possibility of producing them according to the principles of a closed circuit.

This significantly reduces the emission of carbon dioxide to the atmosphere – it is emitted during the combustion of fuel, but then captured by plants and used in their life processes. These processes cause the plant to grow, and the carbon captured in the form of carbon dioxide is incorporated to form the structure of the plant.

First generation biofuels are produced using conventional methods such as fermentation and esterification. The most frequently mentioned first-generation biofuels are bioethanol as well as methyl and ethyl esters which, when mixed with diesel fuel, form biodiesel. The raw materials used for the production of bioethanol are most often cereals, maize, sugar beets, starch or potatoes (Nowaczek and Plata 2022). Higher fatty acid esters are obtained from oilseeds, including rapeseed. The properties of biodiesels are comparable to those of alternative fuels, and this is a fact that proves the legitimacy of developing technologies for the production of such fuels (Bajdor and Biernat 2011; RenaSci).

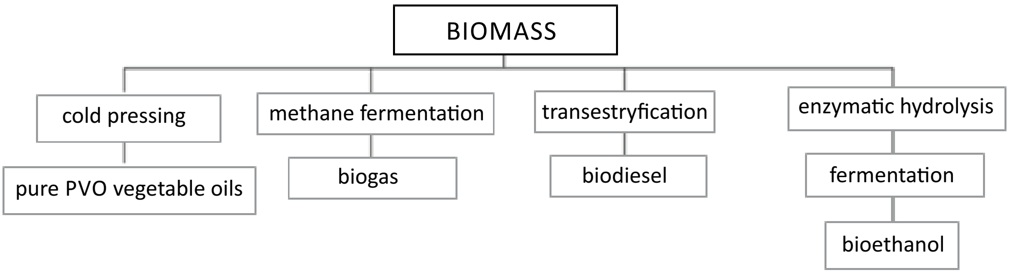

Fig. 2. Diagram of biomass processing

Rys. 2. Przedstawienie możliwości przetwarzania biomasy

RME rapeseed oil esters (Ganguly et al. 2021), methyl esters of higher carboxylic acids FAME (fatty acid methyl ester) or ethyl esters of these FAEE (fatty acid ethyl ester) acids, is produced by cold pressing, extraction and esterification. After these esters are produced, they must be subjected to a process of chemical purification and dehydration. All this is done so that pure compounds can be added to diesel fuel in an earlier developed and tested proportion. It is also possible to use them independently as a given biofuel; however, this requires adding some sort of supplements. Bioethanol, on the other hand, as an alcohol obtained from vegetable biomass containing sugars and large amounts of starch in its structure, can be, after appropriate engine adaptation, a separate fuel or an addition to classic ethylene.

The bioethanol production process is based on anaerobic fermentation. Due to the fact that it has an oxygen atom in its structure, its presence in the rootstock significantly reduces the concentration of harmful hydrocarbons and carbon monoxide in the staples. This fact additionally increases the octane number, which directly translates into the performance of the drive unit. To the group of first generation fuels, we can include those additionally purified from toxic volatile organic pollutants such as hydrogen sulphide or vinyl chloride biogas and PVO (pure vegetable oil) fuels. These are vegetable oils obtained by cold pressing which, depending on the quality and degree of purification, become just fuels or a product intended for consumption or food processes. Moreover, they can be the starting point for the production of the aforementioned biodiesel (Jeswani et al. 2020).

First-generation biofuels are produced from organic substances contained mainly in plants used in parallel to the production of food for humans or animal feed. This creates a kind of problem, as creating competition for such an important sector of the economy is dangerous and may cause resource shortages for both purposes and an increase in the prices of both products (World Bank via Guardian). In addition, this is related to a moral dilemma whether the use of agricultural land intended for food production to obtain materials constituting substrates for fuel production is the appropriate way, especially in times of a deepening global food crisis (Singh and Bharj 2019).

This occurrence and the unfavorable properties of first-generation fuels such as FAME, such as a lower heat of combustion than hydrocarbon fuels and the inability to transport them via pipelines, resulted in creating a need for second-generation fuels on the market (Bioren 2023). It was they who were supposed to solve or at least simplify these problems. They are characterized by the anticipated possibility of reducing greenhouse gases emitted into the atmosphere (Hannon et al. 2010). However, one of the unresolved issues was, at the beginning, the further use of agricultural land for oilseed plantations as substrates for the production of biofuels. Therefore, it was necessary to establish a source of material for the production of this type of fuel, which did not require high-quality soils for its cultivation, or at least was not a food plant (BioEnergy 2023). The ideal candidate turned out to be cellulose products derived from wood processing, perennial grasses, straw and agricultural waste. Second generation biofuels are likely to be more resilient than food crops since their feedstock comes from marginal lands that are more close to natural (Jakóbiec and Wolszczak 2010). The undoubted advantage of the second-generation biofuels is the possibility of using a given plant or waste as a whole. It transpires that it is not necessary to separate the oily parts from them. Woody stems, leaves, roots and even shells can be used to carry out the process. Such cellulose material, suitably cleaned of impurities, is subjected to thermochemical or only chemical treatment processes. In this way, it is possible to obtain Bio-oils, biogas, bioethanol and the so-called *greendiesel*. "In principle, the concept of the development of second-generation biofuels is based on the assumption that the raw material for their production should be both biomass and waste substances of organic origin, useless in the food or forestry industry" (Chye et al. 2018).

However, research has led to the discovery of a plant that does not create competition between the food and biofuel sectors. Linseed (*Camelina sativa*), which as an organism is resistant to bad soil conditions, is highly resistant to unfavorable weather conditions and is an excellent source of vegetable oil, which after processing becomes a promising second-generation fuel.

Its cultivation does not require logging, fertilizing or a huge amount of water. *Camelina sativas* resistance to drought or to soil poor in organic compounds, combined with the fact that it contains 33% more fat than rape, are undoubtedly its great advantages. The possibility of growing an oil plant on unsuitable low-class soils makes it possible to obtain substrates for biofuels without adversely affecting food production on soils of better quality. The second generation biocomponent is obtained from linseed oil using the hydro-conversion process with the petroleum fraction (Singh and Bharj 2019).

On February 22, 2013, the US Environmental Protection Agency approved Linseed Oil as a substrate for biodiesel production. This fuel is defined as an advanced biofuel that meets the

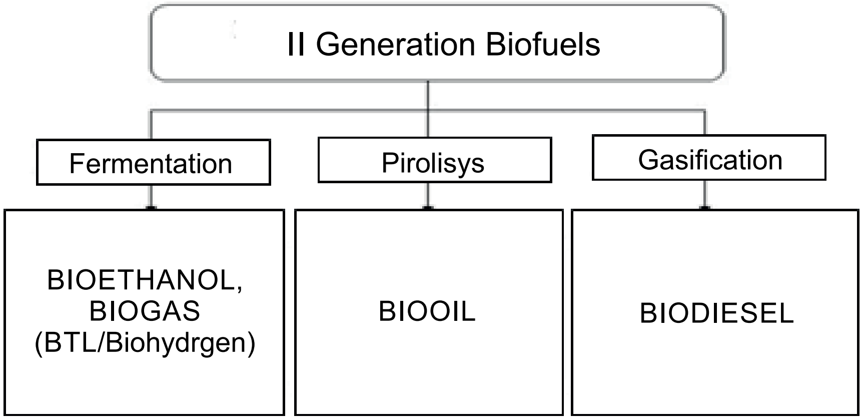

Fig. 3. Division of 2nd generation fuels

Rys. 3. Podział paliw II generacji

RFS guidelines, including providing a 50% reduction in greenhouse gases in relation to fossil fuels (Fekete 2013).

The Directorate General of Transport and Energy of the European Commission proposed some time ago to separate the third generation of biofuels. In principle, they were to be technologically developed and implemented for common use in the years 2030 and beyond; however, for several years now, an increase in the amount of research and proposals for this type of fuel has been observed (Pishvaee et al 2021). Their gradual implementation is aimed not only at stopping and resetting the emission balance but also at reducing the amount of excess carbon in the atmosphere.

Third-generation biofuels are mainly obtained from algae and the majority of them are biohydrogen and bioethanol. The development of the third generation of fuels of biomass origin is due to the fact that these fuels, in addition to reducing GHG emissions, can also capture carbon dioxide (Park et al. 2012). Algae, which are the main matter used in the production of these substances, also have this ability. Due to their specific structure and physicochemical properties, these organisms are able to produce not only fuel substances that are a low-emission source of energy for engines but are also capable of capturing harmful carbon dioxide from the air. They use it for growth and life processes, and they produce oxygen (under sulfur-free conditions – hydrogen), due to which, their emission balance is kept on the minus level. A characteristic feature of algae used for this purpose is their high growth rate.

Third-generation biofuels are considered to be visionary and future-oriented fuels classified as *advanced fuels*. This name means that despite their development nowadays, the effects of their introduction to the market will only be noticeable in the future.

The great advantage of algae as sources of biofuel is the possibility of growing them in almost any conditions that provide access to the basic substances it needs, i.e. light and carbon dioxide. An excellent source of carbon dioxide can be, for example, a conventional power plant – after burning the fuel, the carbon dioxide goes to the algae tank, where it is used for growth. They can grow on polluted water, including sewage, which they purify at the same time. These organisms can be grown in nutrient-poor areas, even in wastelands and deserts. The latter, due to the high level of sunlight, additionally accelerate the entire process of their functioning (Singh et al. 2021).

The ratio of the compounds they produce converted into energy in relation to the land used for their breeding is highly favorable. The area on which they are grown produces as much as thirty times more energy per unit than the unit of cultivation of plants using first- or second-generation fuels. According to the calculations of the US Department of Energy, to cover the entire current US fuel demand, it is enough to grow algae in an area of just 40,000 square kilometers, which is the equivalent of 0.2% of the entire territory of the country.

Moreover, algae, as a genetically well-known group of organisms, are increasingly becoming the subject of research by genetic engineers. The development of appropriate genetic modifications of algae may in the future result in the creation of such a variety that could capture carbon dioxide straight from factory chimneys, immediately transforming it into biogas that can be used to generate energy, be it either heat or electricity. Geneticists are also exploring the possibility of creating microorganisms that can produce hydrogen using sunlight in the process of photolysis.

The technology of genetically modifying algae used for air purification and biogas production is already highly advanced and offers great opportunities. A prime example is the company GreenFuel of Cambridge, Massachusetts, USA. It already offers algae plantations that convert up to 40% of the carbon dioxide emitted by power plants into a raw material for the production of biofuels. The company states that a large algae plantation, working in conjunction with a 1 GW conventional power plant, is able to supply over 150,000 tonnes of ethanol annually.

Interestingly, the algae do not have to become waste after they are used to produce biofuels. Due to the fact that they contain proteins, lipids, hydrocarbons and other nutrients in their structure, algae, in later stages, can be used as food for farm animals or as a natural fertilizer. Using them to improve the quality of soils can make it easier to produce energy crops in low-quality areas, so that you do not have to choose between growing food and energy crops in fertile areas. Subjecting algae as a biomass material to hydrothermal carbonization or pyrolysis processes may result in the production of certain amounts of biochar, which is already used in many economic sectors. Sequestering it would make the whole process even more carbon negative.

Due to the vision in which the economy is emission free, another group of biofuels was introduced – Category IV. These fuels, by definition, are being produced in accordance with the assumptions of the CCS technology (carbon capture and storage). These assumptions are intended to finally close the entire carbon cycle in industry. The raw materials for their production are to be plants with increased CO_2 assimilation, even genetically. Technologies used throughout the production cycle must also take into account the process of capturing carbon dioxide in relevant geological formations. This is supposed to be done by leading the dioxide to the carbonate stage or possibly storing it in oil and gas workings.

Europe and the United States are pioneers when it comes to the development of production technologies and planning at the scientific level of modern fuel solutions. The most promising technologies for future biofuels are:

- The production of JET fuels by means of sunless production of algae from sludge, e.g. agricultural sludge, with the use of carbon dioxide. This technology is called SOLAZYME (Lin and Lu 2021).
- Plasma gasification of waste biomass and the processing of the obtained biosyngases into diesel oils and JET fuels. This kind of technology is called SOLENA.
- Bio-refineries and technologies of using carbon dioxide for production in the production processes of energy carriers.

The development of the biofuel market, their technologies and modern solutions is a very important economic aspect, especially in the era of subsequent directives and regulations aimed at reducing greenhouse-gas emissions. The process of making new designations, types and generations of biofuels is also beneficial. Disadvantages may arise with the development of one of the fuel generations. A good example is the first generation biofuels, which at the very beginning, right after their patenting, were considered to be highly ecological. Today, they turn out to be not as perfect as they were believed to be. Their EROEI indicator (energy returned of energy invested) turned out to be not much higher than 1, sometimes not even reaching the value of 1.0. Of course, this does not apply to all fuels, but the exceptions are few and far from being able to pull the balance (Kurczyński et al. 2021).

Scientific reports, as well as the World Bank and OECD, state that the cultivation of plants for biofuels, especially in the USA and Europe, does not solve either the issue of CO_2 emissions

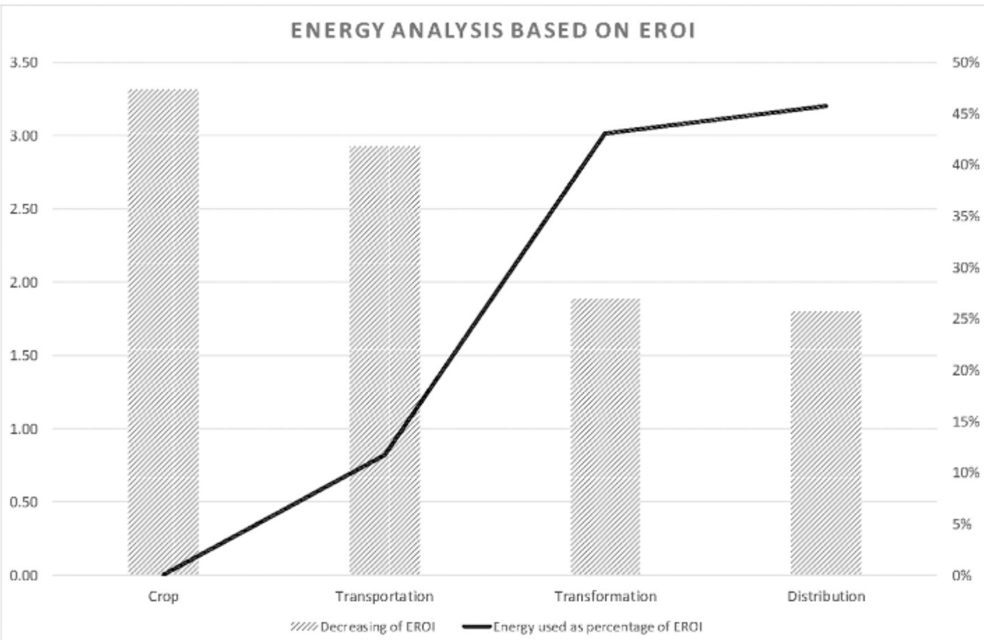

Fig. 4. Decrease in the EROI due to the use of the Energy neccessary per stage- sugar cane (Chiriboga et al. 2020)

Rys. 4. Wartość wskaźnika EROI ze względu na ilość energii niezbędnej na etap trzciny cukrowej or the problem of fuel shortage, but it exacerbates the food crisis. Biofuels today represent the equivalent of 1.5 million barrels per day on the market, and as the World Bank estimates, by taking agricultural land and replacing food crops, they have caused 75% of the 2002–2008 dramatic increase in food prices (Rostek 2011). In order to produce ethanol for one tank of fuel, enough corn to provide food for one man all year round is required. A further increase in land for biofuels would spell a food disaster. The production of biofuels also means increasing the pressure on water resources – the production of 1 liter of biofuels requires using nearly 9,000 liters of water.

Thus, the development of second-, third- and even fourth-generation biofuels is a great opportunity to find alternatives to conventional fuels. Their share in the total production on the biofuel market is growing, investors appear and consortia are increasingly being formed. More and more companies and scientific institutions are involved in the production of biofuels, especially second- and third-generation biofuels on closed cycles, using various energy sources to produce organisms that produce biofuel substrates.

Another chapter in the broad biofuel market is drop-in fuels. These are a group of fuel additives mixed in various proportions with conventional fuels, which may prove to be the most sensible option to reduce emissions from transport. The production cycle of these types of biofuels is currently being developed by an international scientific and technological consortium – BioRen.

2. The BioRen project as the future of biofuels

BioRen is an international consortium founded in 2018, consisting of both scientific and technological induction (Jęczmionek 2010). It responds to the global ecological crisis, assuming a solution to the problem on many levels. The project brings together entities from the broadly understood ecology, waste management and processing industries. Shoulder in the frame with the DC Corporate Finance company, which is the link that supervises the financing and logistics of the project, and the Belgian company RenaSci, the group includes companies from the Netherlands, Spain, Sweden and the Institute of Mineral and Energy Management of the Polish Academy of Sciences. The entire patented technology is implemented in a modern waste-treatment plant of the previously mentioned company, RenaSci.

The main goal of the project subsidized under the Horizon 2020 program of the European Commission is to develop a closed cycle of processing municipal waste into drop-in biofuels. By opting for the use of a closed circuit, future beneficiaries of this solution will be able to process the organic fraction of municipal waste into various types of biofuels (both solid, liquid and gaseous) completely emission-free. A zero emission balance, however, is not the maximum of the possibilities assumed by the entire scheme. After the production of second-generation, drop-in-type biological fuels, modern and ecological wood pellets and other substances that are substrates for the production of other energy carriers, the entire emission balance may even assume a negative value. This fact is exacerbated by the use of a large majority of municipal waste fractions and the separation of biomass material from them, which positively influences waste storage and processing that is often expensive and difficult to maintain in non-emission conditions. This process, in addition, improves the overall garbage segregation mechanism. Of all municipal waste, only plastic and glass are not processed into biomass material, which greatly facilitates the process of screening and sorting these materials after the screening stage. However, even for them, the BioRen consortium envisioned a way of reusing.

The greatest advantage resulting from the production of biofuels from waste is the elimination of problems related to the cultivation of energy and biomass plants on considerable areas of agricultural land. Their breeding, in addition to the compulsory fertilization, watering and gradual sterilization of these areas, created competition for food plants. At a time when the climate crisis was developing simultaneously with the nutritional crisis, the elimination of such a problem was extremely necessary. Additionally, when producing biofuels, especially first and second generation biofuels from plants and biomass materials specially cultivated for this, the entire logistic process related to the production, transport and processing of these materials emitted slightly lower levels of greenhouse gases than the extraction and energy conversion of conventional fossil fuels. Comparing the EROI/EROEI (energy return on energy invested indicator) balance values of the two processes gives a clear picture of which one assumes greater energy efficiency. Adding to this the lower emissions of the energy production system assumed by the BioRen consortium, it is easy to conclude which process is more refined and responds better to the current global problems. Garbage, as a renewable and in a certain way inexhaustible source, at the same time constituting a huge deposit rich in carbon materials, is an excellent alternative to the current methods of producing modern biofuels.

Table 1. Basic information about the project

Tabela 1. Podstawowe informacje dotyczące projektu

Plant name	Type PP, DP or CP	Status	Start-up Year	Biomass type	Feedstock capacity [tonnes/year]	Product [tonnes/year]	By product	Hours in operation
Renasci, Ostend, Belgium	DP	under comstruction	2021	organic fraction of industrial & MSW (paper/car dboard)	40,000 tonnes paper+card board/year (from 120,000 tonnes waste/ year)	ethanol, isobutanol, GTBE, biobased chemicals	biocoal pellets	–

The technological process itself, which is the basis of the BioRen project developed by RenaSci, involves the collection of the solid fraction of municipal waste and processing it into reusable materials such as glass, iron, non-ferrous and hard plastics. In the first phase, the organic fraction is isolated from other waste in a pilot plant using a fully automated sorting plant with a combination of several separation techniques, such as wind screening, drum screening or magnetic separation. Materials that cannot be subjected to complicated recycling processes are separated into organic components, plastic and all the rest. Plastic is processed in accordance with the principles of P2C technology. This thermal process breaks down the plastic polymer into oil, which is used as a raw material in the production of new plastics. The main by-product of this process is used as fuel to generate electricity for the facility. This is so-called E850 Diesel. Waste containing neither plastic nor an organic fraction in its structure is also processed into various types of materials that are additives to building materials.

The organic fraction, on the other hand, is treated on the basis of technology developed by the BioRen consortium. Here, the waste material containing biomass is subjected to mechanical, chemical and enzymatic treatment. After the material is crushed, it is treated with cellulase, which hydrolyzes cellulose to simpler sugars. The suspension, which is a sugar-rich solution, separated from the rest, is subjected to ferentiation, which produces isobutanol and bio-ethanol. These are the basic substrates for the production of bio-GTBE, which is a modern second-generation fuel.

After distillation, the fermentation sludge is processed in Ingelia pilot plants in a slightly acidic environment at a temperature of approx. 200°C for 1 hour and at a pressure of 18 bar. This technology is called HTC hydrotemal carbonization and is an innovative method of obtaining biochar that is much more economical and efficient than pyrolysis. Its advantage over other thermochemical processes is the possibility of using wet material. Pre-treatment or drying is not required, which additionally reduces energy consumption throughout the cycle. The BioRen Consortium provides for the production of biocarbon pellets as an alternative to traditional heating fuels. Biocarbon materials obtained by hydrothermal carbonization are characterized by a calorific value of 24 MJ/kg, lower sulfur and nitrogen content, high carbon content and a high level of hydrophobicity. This results in reduced greenhouse-gas emissions while maintaining a high energy balance of this material. Biocarbon materials, which, however, for various reasons, even too much fragmentation, cannot be processed into pellets, are used in soil fertilization. In addition to improving their quality, this action causes carbon sequestration in the soil, which reduces the amount of carbon in the atmosphere.

The biggest advantage and the reason to be proud of the whole project is the SCP concept (smart chain processing). The idea is to conduct the entire process of processing waste into various types of products on the principle of a closed circuit, with the simultaneous logistic connection of various technologies inside the entire "cycle wheel". This means that products such as biochar, biosyngas, and third-generation fuels or bio-oils produced during this one process are used to drive the steps in the others that need this energy. The seamless integration of different waste treatment technologies under one roof enables the valorization of complex waste streams that would otherwise not be cost effective to recycle. In addition, the entire process, including wastewater treatment, becomes energy self-sufficient thanks to energy recovery from waste heat. The heat and electricity generated during the recycling process are the main energy factors that keep the entire system chain running, and in addition, this heat feeds RenaSci's wastewater treatment plants.

Returning to the main product of the entire process, which are biofuels, especially bio-GTBE, it is worth taking a closer look at this substance. Isobutanol and Bioethanol are substrates required for its production. However, they also need to be properly reacted with each other. Apart from them being obtaining from the solid fraction of municipal waste, BioRen is also developing a method of their production from specially modified strains of 2G Sacharomyces. After receiving both of these substances, the process of chemical dehydration takes place, which results in obtaining isobutylene. Together with glycerol Category 1, this is the main substrate for the production of bio-GTBE.

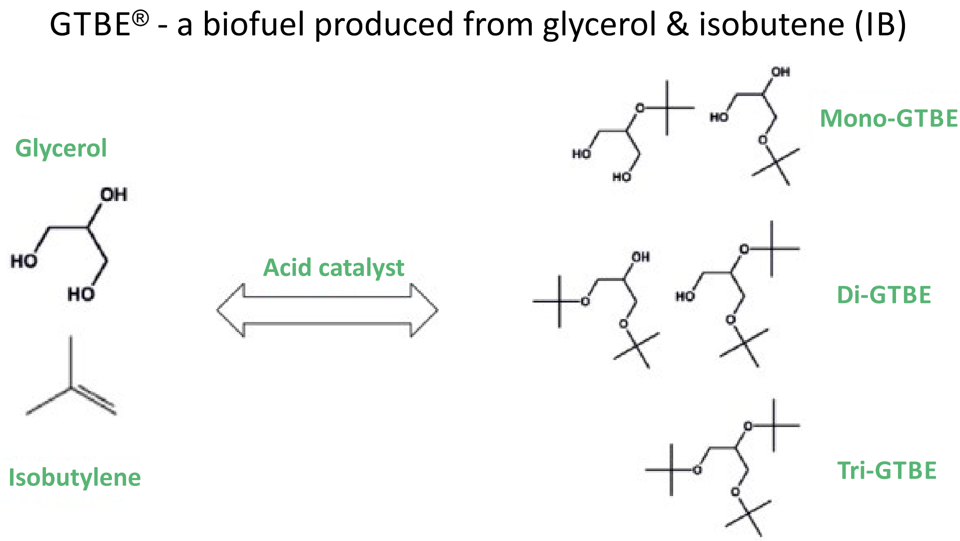

Fig. 5. The reaction of the formation of compounds forming bio-GTBE

Rys. 5. Reakcja tworzenia składników tworzących paliwo bio-GTBE

The mixture of various ratios and combinations of glycerol tert-butyl esters creates second-generation drop-in biofuel. This is a promising form of fuel material that can be added to conventional fuels such as ethylene and diesel in greater amounts than ethanol. Its use does not force the consumer to convert the car engine. Fuel tests, both on a laboratory and industrial scale, have shown that the addition of bio-GTBE to traditional fuels does not have a negative impact on the service life of the engines (Esmaeili et al. 2020). On the contrary, it increases their efficiency and driving economy while reducing the emission of environmentally harmful greenhouse gases and fine dust emitted during the combustion of fuels at present. It has also been proven that this biofuel increases the octane number of the fuel to which it is added (Singh and Bharj 2019).

Conclusion

All those aspects mean that the BioRen consortium has developed a technology that operates on the basis of a closed cycle, producing both transport fuels and heating fuels such as biochar. Their wide range of use causes a significant decrease in the emission of greenhouse gases and substances that are harmful to the environment. At the same time, garbage is the substrate for the production of all these substances. This significantly reduces the scale of the problem of their segregation, transport and management. Due to their gradual use, no harmful substances are emitted into the soil or groundwater, and even the release of methane into the atmosphere is prevented. In its complex technological interconnections, the BioRen project ameliorates the global ecological crisis on many levels, perhaps not interconnected at first glance. The companies and institutions that make up BioRen have shown enormous opportunities that result from technologies currently known to us. This fact and the entire success of the project, despite the fact that it continues until the end of 2022, are a good sign in the context of the ecological crisis situation in the world. Despite the lack of precise data on the results and figures related to the project, the development and gradual introduction of similar technologies to the market can be assumed.

The discussed progress seems to be just the beginning. Circular-economy projects involving the introduction of developmental and future technologies in order to combat global problems should be created, subsidized and supported increasingly often. It is also worth involving various types of small startups. Conducting training programs and courses for employees from the industry and students can also bring tangible results for the future.

References

Bajdor, K. and Biernat, K. 2011. Biofuels as alternative energy carriers in IC engines; classification and development prospects (*Biopaliwa jako alternatywne nośniki energii w silnikach spalinowych, klasyfikacja i perspektywy rozwoju*). *Archiwum Motoryzacji* 1, pp. 123–137 (*in Polish*).

Bhuiya et al. 2016a – Bhuiya, M.M.K., Rasul, M.G., Khan, M.M.K., Ashwath, N. and Azad, A.K. 2016a. Prospects of 2nd generation biodiesel as a sustainable fuel – Part: 1 selection of feedstocks, oil extraction techniques and conversion technologies. *Renewable and Sustainable Energy Reviews* 55, pp. 1109–1128, DOI: 10.1016/j.rser.2015.04.163.

Bhuiya et al. 2016b – Bhuiya, M.M.K., Rasul, M.G., Khan, M.M.K., Ashwath, N., Azad, A.K.and Hazrat, M.A. 2016b. Prospects of 2nd generation biodiesel as a sustainable fuel – Part 2: Properties, performance and emission characteristics. *Renewable and Sustainable Energy Reviews* 55, pp. 1129–1146, DOI: 10.1016/j.rser.2015.09.086.

BioEnergy 2023. [Online] www.bioenergyinternational.com [Accessed: 2022-10-05].

Bioren 2023. [Online] www.bioren.be [Accessed: 2022-11-25].

Breakdown of CO_2 emissions in the transportation sector worldwide 2020, Ian Tiseo, 2021.

Chiriboga et al. 2020 – Chiriboga, G., De La Rosa, A., Molina, C., Velarde, S. and Carvajal, C.G. 2020. Energy Return on Investment (EROI) and Life Cycle Analysis (LCA) of biofuels in Ecuado. *Heliyon* 6(6), DOI: 10.1016/j.heliyon.2020.e04213.

Chye et al. 2018 – Chye, J.T.T., Lau, Y.J, Yon, J.L.S., Pan, S. and Danquah, M.K. 2018 – Biofuel production from algal biomass. [In:] *Bioenergy and Biofuels*, pp. 87–117, DOI: 10.1201/9781351228138-3.

Directive of the European Parliament and of the Council (EU) 2018/2001, 2018.

Esmaeili et al. 2020 – Esmaeili, S.A.H., Szmerekovsky J., Sobhani, A., Dybing, A. and Peterson, T.O. 2020. Sustainable biomass supply chain network design with biomass switching incentives for first-generation bioethanol producers. *Energy Policy* 138, DOI: 10.1016/j.enpol.2019.111222.

Fekete, B.M. 2013. Climate Vulnerability Understanding and Addressing Threats to Essential Resources. *Earth Systems and Environmental Sciences* 3.

Ganguly et al. 2021 – Ganguly, P., Sarkhel, R. and Das, P. 2021. The second- and third-generation biofuel technologies: comparative perspectives. *Sustainable Fuel Technologies Handbook*, pp. 29–50.

Hannon et al. 2010 – Hannon, M., Gimpel, J., Tran, M., Rasala, B. and Mayfield, S. 2010. Biofuels from algae: challenges and potential. *Biofuels* 1(5), pp. 763–784, DOI: 10.4155/bfs.10.44.

Jakóbiec, J. and Wolszczak, J. 2010. Prospects, barriers to growth and technical conditions for the exploitation of biofuels (*Perspektywy, bariery wzrostu i uwarunkowania techniczne dotyczące eksploatacji biopaliw*). Konferencja projektu Alter-Motive Poświętne – Prezentacja (*in Polish*).

Jeswani et al. 2020 – Jeswani, H.K., Chilvers, A. and Azapagic, A. 2020. Environmental sustainabilityof biofuels: a review. *Proceedings of the Royal Society A* 476, DOI: 10.1098/rspa.2020.0351.

Jęczmionek, Ł. 2010. Camelina oil (*Camelina sativa*) – a chance for the second generation bio-fuels expansion? (*Olej z lnianki siewnej (Camelina sativa) – szansa rozwoju biopaliw II generacji?*) *Nafta-Gaz* 66/9, pp. 841–848 (*in Polish*).

Kargbo et al. 2021 – Kargbo, H., Harris, J.S. and Phan, A.N. 2021. “Drop-in” fuel production from biomass: Critical review on techno-economic feasibility and sustainability. *Renewable and Sustainable Energy Reviews* 135, DOI: 10.1016/j.rser.2020.110168.

Kurczyński et al. 2021 – Kurczyński, D., Łagowski, P. and Wcisło, G. 2021. Experimental study into the effect of the second-generation BBuE biofuel use on the diesel engine parameters and exhaust composition. *Fuel* 284, DOI: 10.1016/j.fuel.2020.118982.

Lin, C.-Y. and Lu, C. 2021. Development perspectives of promising lignocellulose feedstocks for production of advanced generation biofuels: A review. *Renewable and Sustainable Energy Reviews* 136, DOI: 10.1016/j.rser.2020.110445.

Nowaczek, A. and Plata, P. 2022. The use of new generation fuels, on the example of the BioRen project (*Wykorzystanie Paliw nowej generacji, na przykładzie projektu BioRen*). Poster (*in Polish*).

[Online] RenaSci, BioRen, BioBaseEurope.com, ec.europa [Accessed: 2022-10-05].

Park et al. 2012 – Park, S.H., Cha, J. and Lee, C.S. 2012. Impact of biodiesel in bioethanol blended diesel on the engine performance and emissions characteristics in compression ignition engine. *Applied Energy* 99, pp. 334–343, DOI: 10.1016/j.apenergy.2012.05.050.

Pishvaee et al 2021 – Pishvaee, M.S., Mohseni, S. and Bairamzadeh, S. 2021. Chapter 1 – An overview of biomass feedstocks for biofuel production. *Biomass to Biofuel Supply Chain Design and Planning Under Uncertainty. Concepts and Quantitative Methods*, pp. 1–20, DOI: 10.1016/B978-0-12-820640-9.00001-5.

Rostek, E. 2011. Biofuels of first and second generation – methods for receiving and properties (*Biopaliwa pierwszej i drugiej generacji – metody otrzymywania i właściwości*). *Logistyka* 6 (*in Polish*).

Singh, G.N. and Bharj, R.S. 2019. Study of physical-chemical properties for 2nd generation ethanol-blended diesel fuel in India. *Sustainable Chemistry and Pharmacy* 12, DOI: 10.1016/j.scp.2019.100130.

Singh et al. 2021 – Singh, D., Sharma, D., Soni, S.L., Inda, C.S., Sharma, S., Sharma, PK. and, Jhalani, A. 2021. A comprehensive review of physicochemical properties, production process, performance and emissions characteristics of 2nd generation biodiesel feedstock: Jatropha curcas. *Fuel* 285, DOI: 10.1016/j.fuel.2020.119110.
World Bank via Guardian.

Piotr Jan Plata, Agnieszka Nowaczek

Projekt BioRen w kontekście rozwoju paliw nowej generacji

Streszczenie

W dobie otaczającego nas kryzysu klimatycznego udoskonalanie technologii odpowiedzialnych za emisję największych ilości gazów cieplarnianych jest konieczne i coraz częściej wymagane odgórnymi regulacjami. Sektor paliwowy, jako ten odpowiedzialny w dużej mierze za światową logistykę i łańcuchy dostaw, jest jednym z najbardziej badanych pod względem ograniczania jego szkodliwego wpływu. Rozwój kolejnych generacji paliw i biopaliw, produkowanych przez firmy stosujące coraz nowocześniejsze, czystsze emisyjnie i zrównoważone technologie jest w stanie znacząco wpłynąć na obniżenie ilości gazów cieplarnianych do atmosfery. Najefektywniejszym rozwiązaniem wydaje się w tym wypadku zastosowanie obiegów zamkniętych. Ze względu na ich niski, często zerowy, bilans emisyjny oraz możliwość wykorzystania odpadów do produkcji materiałów, które mogą zostać ponownie wykorzystane, obiegi zamknięte znajdują zastosowanie w wielu sektorach gospodarki, zapewniając jednocześnie czystość emisyjną procesów technologicznych.

Jednym z innowacyjnych rozwiązań, zaproponowanych w ostatnich latach, jest instalacja powstała w ramach projektu BioRen, realizowanego w ramach programu Horyzont 2020. Współpraca europejskich instytutów z firmami sektora MŚP zaowocowała powstaniem eksperymentalnego cyklu nowoczesnych technologii produkcji biopaliw drugiej generacji. Projekt zakłada przetwarzanie stałych odpadów komunalnych w biopaliwa II generacji typu *drop-in*. Cały schemat procesu zakłada, oprócz produkcji biopaliwa, przetwarzanie frakcji nieorganicznych, produkcję materiału węglowego do produkcji energii cieplnej a także jednoczesne oczyszczanie ścieków.

Słowa kluczowe: zarządzanie odpadami, energia, biopaliwa, gospodarka o obiegu zamkniętym, BioRen