Energy Efficient Renewable Feedstock for Alternative Motor Fuels Production: Solutions for Ukraine

Anna Yakovlieva and Sergii Boichenko

Abstract The presented study is devoted to assessment of renewable feedstock for alternative fuels production with relation to quality parameters, agrotechnical parameters, environmental impact and overall sustainability of possible feedstock. The state-of-art of the modern transport sector is shown, as well as the need in fostering implementation of biofuels for road and air transport. Rapeseed and camelina oils are considered as two of the most profitable sources for biofuels production in Ukraine. The comparative analysis of quality and agrotechnical parameters was done. Taking into account requirements to sustainability it is recommended to develop cultivation of camelina in Ukraine as a feedstock for biofuels production.

Keywords Motor fuel · Jet fuel · Biofuel · Renewable feedstock · Rapeseed oil · Camelina oil · Environment

1 Introduction

The rapid development of the world economy is accompanied by high rates of primary energy consumption. In recent years, global consumption of major energy sources of industrial value has exceeded 10 billion tons/year [1].

The significant increase in number of road transport in recent years has led to a great demand for petroleum products. However, oil reserves are estimated to last only a few decades. As a consequence, depletion of oil reserves will have a significant impact on the transport sector. In this regard, today in the world there is an active search for alternative fuels [1]. The use of biofuels instead of conventional fuels is a rather urgent problem for our country, in particular, since Ukraine belongs to energy-scarce countries and has relatively low oil and gas reserves.

The main consumer of fuel worldwide is road transport (2575 million as of 2017) [9]. In the structure of road transport of Ukraine, cars with gasoline engines (more

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than 85%) are predominant, there are about 13% of diesel vehicles and less than 1.5% of gas tanks [9].

Transport as a sector of the economy is one of the most powerful factors of anthropogenic impact on the environment. Some types of this impact, such as air pollution and noise pollution, are among the most serious man-made loads on environmental components of particular regions, especially large cities [2, 9].

With increasing concern about reducing fossil energy resources and minimizing environmental footprint, there is increasing interest in exploring alternative energy sources, including alternative motor fuels or biofuels.

Today, one of the promising areas of research in the field of transport and its related fuel supply is the development of alternative environmentally friendly motor fuels from renewable raw materials of plant origin. The use of such fuels will help reduce the anthropogenic load on the environment, reduce the amount of CO_2 emissions into the atmosphere (both in the process of fuel production and their use). In addition, it will reduce the dependence of a number of countries on imports of petroleum products and other energy resources [12, 13].

Given the rapid development of technology, there is a wide variety of alternative motor fuels in the world today. In particular, biofuels have become widespread; primarily due to the ability to overcome the ongoing climate change caused by carbon dioxide emissions and reduce our dependence on oil resources. Over the last decades, scientists have been exploring the use of various types of biomass for biofuels.

2 Generations of Alternative Motor Fuels

The search and widening of new feedstock, development of progressive technologies of alternative fuels production and their rational use in transport, is one of the priority tasks nowadays. The advantages of renewable energy are: natural origin, rapidity of renewal, absence of extra CO_2 emissions, less negative impact on environment, easy biodegradation in nature. At the same time alternative fuels from renewable feedstock must meet the requirements connected to efficiency, reliability and durability of transport [5–8].

Today there is a great variety of renewable feedstock or biomass for alternative fuels production [4]. Biomass-derived alternative fuels can provide a near-term and even a long-term solution to the transport industry with a lower environmental impact than petroleum fuels.

Potential feedstock for producing alternative fuels are classified as:

- *oil-based feedstocks*, such as vegetable oils, waste oils, algal oils, and pyrolysis oils,
- *solid-based feedstocks*, such as lignocellulosic biomass (including wood products, forestry waste, and agricultural residue) and municipal waste (the organic portion),
- *gas-based feedstocks*, such as biogas and syngas.

The key to the successful implementation of alternative fuels is the availability of feedstock at a large and sustainable scale and low price. Improved yields and reduced plantation or transportation costs would promote commercialization of alternative fuels conversion processes and, therefore, would allow the industry and government to assess and address the feedstocks' potential and impacts [4, 13–15].

It is obvious that each kind of feedstock requires certain technology of its processing. Some of them are already popular and some are still developing. According to the complexity and the level of maturity these technologies are traditionally classified according to generations (Fig. 1).

First generation of alternative fuels (biofuels), which are widely popular today, are produced from traditional agricultural plants. Plant oil-derived biofuels are produced by esterification of traditional oil-containing plants (rape, soya, sunflower, palm, etc.). Ethanol is produced by fermentation of the sugar or starch contained in plant biomass.

Second generation of biofuels is produced by processing the whole plant—particularly its lignocelluloses, the main component of plant cell walls. The resource is available in large quantities in a variety of forms: wood, straw, hay, forestry waste, plants' residues, etc. second generation processes do not compete with food uses. Two processes are being studied: biochemical conversion and thermochemical conversion [3, 13].

Third generation of biofuels can be produced using either autotrophic (operating via photosynthesis) algal biomass or heterotrophic process (operating via the supply of an external carbon, such as sugar). Except that third generation biofuels foresee applying the already known technologies for new kinds of oil-containing feedstock, which do not compete with food industry (jatropha, camellina, etc.) [15, 16].

Fourth generation biofuels (Fig. 2) are considered only during the last 3–5 years and now still at the early stage of development. They are derived from specially engineered biomass, which has higher energy yields or are able to be grown on non-agricultural land or water bodies. Biomass crops are seen as efficient'carbon capturing' machines that take CO_2 out of the atmosphere and 'lock' it in their branches, trunks and leaves. The carbon-rich biomass is converted into fuels by means of second generation techniques. The greenhouse gas is then geosequestered—stored in depleted oil and gas fields, in unmineable coal seams or in saline aquifers, where it stays locked up for hundreds of years [17, 18].

3 Perspective Plant-Derived Components for Alternative Jet Fuels Production

This diversity of technologies provides the ability for alternative fuels production using various feedstocks. Scientists believe that the most promising feedstocks are plants with high oils content, algae and some types of industrial and household waste.

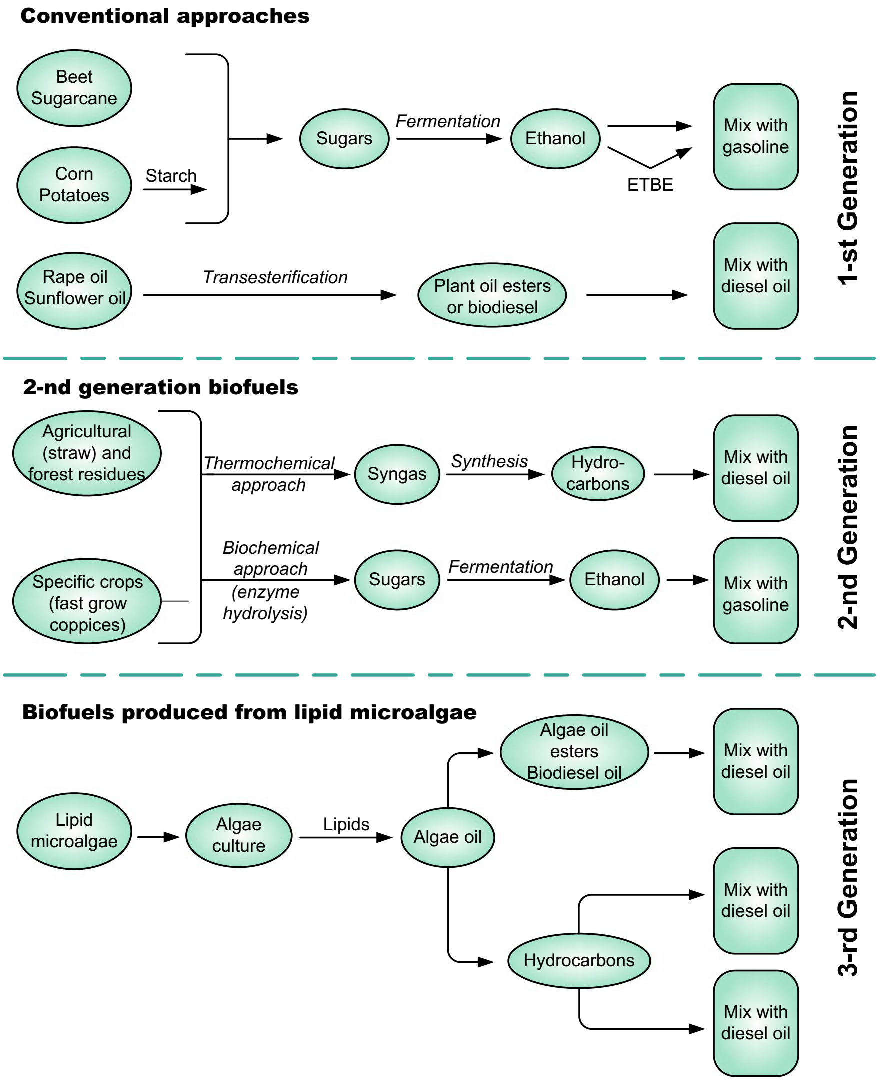

Fig. 1 Development of technologies for biofuels production

Camelina relates to energy crops with high oil content. The main consumers are the producers of biofuels. Camelina cultivation is currently implemented at sufficiently large scale so to achieve a considerable production of crude vegetable oil that will then be converted into paraffinic biofuels (HEFA). Camelina is used in agriculture as crop rotation, which prevents reduction of soil fertility and provides increasing of crop resistance to diseases and pests. It is not demanding to climatic conditions and does not require substantial cultivation and care. Camelina seeds contain 40–50% of

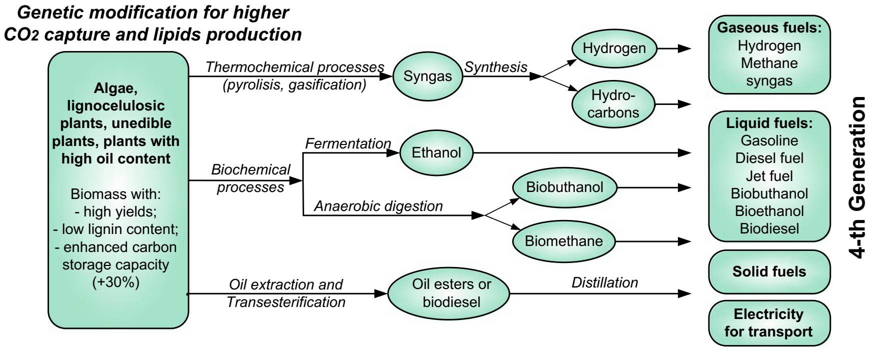

Fig. 2 Technologies for 4th generation alternative fuels production

oil, providing oil output of about 1250 l/ha. Another advantage of this culture is the use of meal as feed for livestock and poultry. The scientists believe these camelina characteristics provide “sustainability” of the process of biofuels production without creating competition in the food industry. Camelina is a very promising crop that is expected to offers a high level of sustainability, that can be grown in EU and elsewhere in marginal land where conventional agriculture is not sufficiently productive to be carried out by farmers.Nowadays this culture is widespread in the US, Canada and some European countries [3, 4].

Rape is considered to be one of the main crops for biofuels during the last 10–15 years. During 2000–2010 years leading producers of rapeseed oil were Canada, the US and European countries such as Germany, France, Czech Republic, Poland, UK. The chemical composition and basic characteristics of rapeseed oil are well suited for alternative fuels. But then the question arose about the necessity of rape cultivation as the main biofuels feedstock. Rape culture is highly depending on growing conditions, needs constant fertilizing and other care while significantly depletes the soil in areas that are traditionally used for agriculture. Analyzing these data, scientists have concluded that rape is competitive in needs of the food industry, and thus the process of production and usage of biofuels will not be sustainable [3]. Numerous researches on selection rapeseed crops with improved physicochemical and agronomic characteristics were held. Thus, the oil content in the seed yield was increased as well as average oil output to 1200–1300 l/ha. The so-called low-erucic breeds with the corresponding fatty acid composition of the rapeseed oil were selected that is the best for biofuels. The scientists were able to increase crop resistance to pests, climatic conditions or other adverse growing conditions, and thus reduce the cost of oil production and fuel respectively. We can conclude that the denial of rapeseed as a feedstock for biofuels is not fully justified [9, 10].

It should be noted that for Ukraine rape is a typical culture, and in the last 8–10 years the massive producing was noticed. The most rapid increase of production volumes of rape occurred in the period 2004–2008 years, which coincided with the growing of global demand for rapeseed oil as raw material for the production of biofuels. This allows us to consider rapeseed oil as the most promising raw materials for motor biofuels.

Jatropha is grown to obtain inedible oil that can be used to produce biofuels. Oil content in the seeds is about 30–40%. It is known that due to the physical-chemical properties jatropha oil is well suited for the production of alternative motor fuels. This culture is not a depending on soil quality and can give good yields in dry uncultivated areas, leaving fertile soils for agriculture. However, the factor that limits the widespread use of jatropha, is the possibility of growing only in warm climates.

Algae are recognized as the most promising raw materials for the production of large amounts of aviation biofuels. These microscopic plants can be grown in salt or fresh water, polluted water bodies, bodies of water in deserts and other uninhabited areas. During the lifecicle algae consume CO_2, which makes them extremely effective tool for the absorption of carbon from the atmosphere produced from burning of fossil fuels. Microalgae are capable for producing up to 15 times more oil on 1 km^2 than other energy crops. The can grow in low-boundary land not used for farming (desert areas).

It might be feasible to convert algae oil directly into green diesel or aviation fuel. Catalytic conversion of second generation oil with hydrogen into paraffins has already been investigated for application in industry.

The most common liquid fuel from algae is Fatty Acid Methyl Ester (FAME) is typically produced by a reaction (transesterification) between triglycerides and alcohol (most commonly methanol) at 60–70 °C and in the presence of an alkaline or acidic homogeneous catalyst at atmospheric pressure. In addition to triglycerides in the lipid fraction, algae oil also contains a substantial quantity of free fatty acids and some moisture. Their occurrence is undesirable for transesterification because in alkaline catalysed reaction, they produce soap and reduce biodiesel yield. In this instance, an acid catalyst is better suited for the purpose as it is able to process low grade feed. Current processes used for manufacturing biodiesel are not entirely suitable for algae oil. A feasible option is to carry out the reaction at high temperature and pressure. The supercritical transesterification of first and second generation oil by various research groups showed almost complete conversion in reasonable reaction time. At supercritical conditions, the reaction can process moisturerich feed with free fatty acids and subsequently eliminate pre-treatment process units. Application of catalyst-free supercritical alcohol transesterification is desirable due to feed stock flexibility and the relatively small reactor volume needed to achieve high production rates.

One of the main advantages of using algae is their massive biodiversity, which makes it possible to select strains for a particular geographical location or a specific purpose. Different algal strains have adapted to grow in UK soil, on the surface of the ocean, underneath desert sand, next to hydrothermal vents, and in freezing Siberian rivers. There is an optimal algal strain for every location. One potential algal application is to capture the CO_2 emitted by fossil fuel combustion in power stations. To achieve this, it is necessary to select an extremophile with high temperature and low pH tolerance, as well as a very active Calvin Cycle.

However, at this stage of development the issue of the best technologies development for algae cultivation is not yet fully resolved. Scientists project this process requires at least 8–10 years.

Halophytes are herbaceous plants that are combined in a separate group due to the possibility of their growth on saline soils (salt marshes and other areas with access to sea water). The using of this type of material is very promising in terms of the idea of sustainability of alternative motor fuels. Today about 20–25% of the Earth is not used for agriculture through increased soil salinity levels. Typical examples of halophytes are rich in unsaturated fatty acids containing 90% of carbon chains in triglycerides. Overall cultivation of halophytes is an important component of the system designed to reduce the amount of greenhouse gases. The use of these plants as a feedstock for the production of aviation biofuels is still at the research stage, but could be widely implemented in 2–4 years.

Household and industrial wastes in recent years are also considered a promising raw material for production of aviation biofuels. Currently factories are actively building, where as a result of complex processes such as waste wood, paper, wood residues, agricultural residues, by-products of livestock, some industrial waste, food waste, municipal sewage and others are processing into fuels. One of the advantages of the use of waste is the ability to ensure the production of biofuels from waste plant material. In addition, recycling of waste into alternative fuels is one of the solutions to the problem of waste recycling that accumulates on numerous landfills.

Used cooking oil (UCO) is another feedstock that is being investigated. Compared to other more traditional oily feedstock, UCO shows a high variability in quality and composition depending on the collection area, the collection method, and the period of the year (when different vegetable oils are consumed). Contaminations in the oil represent a serious technical challenge to be dealt with before catalytic hydrotreatment process [10–12].

The upgrade of crude UCO to a suitable feedstock is an activity that still requires R&D work, and new approaches can be considered. This variability could be reduced by proper pre-treatments. Once collected, UCO is usually filtered and de-watered: water in UCO can create problems in the downstream processes, and is source of damages to plant equipment, enhancing the corrosion.

The water content of UCO is normally reduced by means of paper filters, a cost-effective solution with high removal efficiency. The use a paper filtration contextually reduces the amount of suspended solids. The total contamination has to be significantly reduced, since solids in aviation engines are cause of injector and blade corrosion and erosion, increasing the maintenance engines costs and risks.

Due to vegetable oil cooking processes, and contamination from the food, UCOs usually show high free acidity (1–5%). A common possible mean to improve the UCO quality, reducing acidity without losses in its energy content, is the esterification process. This process, widely used in the biodiesel sector, rebuilds the triglycerides by using glycerine in a dedicated reactor, sometimes in presence of catalysts. However, the interest in this technique depends on the type of downstream processes: this process is normally adopted in the biodiesel sector, where in most of the cases transesterification to biodiesel does not tolerate high level of fatty acids, and could also be of interest for HEFA production.

Today most of scientists claim about such property of alternative motor fuels as its sustainability. Sustainable motor fuels can be considered as sustainable only if they have a substantially better GHG balance than their fossil alternative, do not harm the environment, or involve any negative socio-economic impacts. Not all biomass feedstock are fit to produce sustainable motor fuels. The type and origin of the biomass feedstock largely determines the overall sustainability of the sustainable motor fuels, including the lifecycle of its GHG mainly through production and transport energy needs, use of fertilizers and land-use change effects. Some types of biomass feedstock may actually cause more GHG emissions than conventional fossil motor fuel especially when considering indirect land use change impacts [19–21].

Table 1 presents a summary of the emissions reduction for a number of feedstock. Sustainable motor fuels derived from wastes (such as animal fat and used cooking oil), or based on wood and agricultural residues (such as straw), have significantly lower emissions than those based on conventional oil crops. Sustainable motor fuels from algae can potentially be carbon neutral or even produce a reduction on GHG thanks to the absorption of CO_2 in co-products other than fuel. While these numbers are a useful guide, actual GHG reductions are ultimately dependent on the design of each specific project.

In many cases the cost competitiveness of biofuels therefore depends on the price of feedstock. The cost of feedstock includes the price of raw material and its eventual pre-treatments. Transport costs from the feedstock supplier to the alternative motor fuels plant must be added too. Table 2 shows a selection of the wide range of variables influencing feedstock, logistics and pre-processing costs.

Table 1 Greenhouse gas emissions of Sustainable motor fuels

Technology pathway	Feedstock	Emissions (gCO_2/MJ fuel)	Savings CO_2 versus conventional fuels (baseline)
	Conventional fuel (average value)	87.5	
FT	Wood residues/straw	4.8	95%
HEFA	Conventional oil crops (palm oil, soy, rapeseed)	40–70	20–54%
	Jatropha	30	66%
	Camelina	13.5	85%
	Animal fat	10	89%
	Algae (from open ponds)	– 21 (best case) 1.5 (realistic case)	124% (best case) 98% (realistic case)

Table 2 Variables influencing feedstock, logistics and pre-processing costs

Feedstock costs	Logistics and pre-processing costs
Geographic origin Feedstock type Seasonality (droughts) and availability Level of mechanization and inputs Scale	Distance Accessibility Mode of transportation Technology level Scale

Projects and strategies to increase feedstock yields and to optimize logistics in terms of availability and infrastructure are required to ensure the provision of feedstock at competitive prices.

4 Analysis of Renewable Feedstock Available in Ukraine

High-energy-intensive oil crops are the most attractive source of biodegradable feedstock, which can partially replace traditional crude oil, including in the production of aviation jet fuels. However, the use of traditional oils for technical purposes, in particular for the production of fuel, is significantly restricted. This is due to the fact that such crops as sunflower, soybean, corn, etc. are grown primarily to meet the needs of the food industry. For the same reasons, cultivation of industrial crops, such as rapeseed, is limited to the area available for cultivation. Today, one of the most promising alternative oilseeds, which is characterized by low requirements for growing conditions, is red sowing (Camelina sativa L.) [1, 2]. Camelina culture is very unpretentious to soil quality, climatic conditions, resistant to pests, diseases and cold, does not require a large amount of mineral fertilizers. In shorter duration of the growing season, this crop yields a proportion of rapeseed with the yield of oil per unit area of crop. Short growing season also contributes to the cultivation of camelina as an intermediate crop in post-harvest crops. In addition, growing camelina does not lead to intensive depletion of fertile land [4].

Camelina belongs to the cabbage family Camelina and includes 15 species, of which the most widely cultivated redhead sowing. It is considered to be the least demanding of growing conditions compared to other oilseeds.

Camelina is characterized by high cold resistance (the seed germinates beyond 1 °C, and the seedlings easily withstand freezing to minus 12 °C) and water-time drought resistance. It grows well on all types of soil except clay. One of the main biological features of Camelina is the short growing season, which in most regions of cultivation is 80–85 days (due to which it reaches, and can be successfully grown in all regions of Ukraine), which makes it possible not only to effectively use the moisture reserves in the fall—winter rainfall, but also to form a crop due to rainfall that occurs during the growing season [3, 4].

The short growing season of the Camelina enables it to grow other crops after harvesting, and using it for a busy couple allows it to prepare the soil well and accumulate moisture for winter sowing.

In addition, unlike other cultures of the cabbage family, it is practically not pest-infested and disease-free, and in times of steady increase in energy and pesticide prices, it can significantly reduce the cost of growing it. Camelina is quite a crop crop: its potential yield can be 20–30 centners/ha. Camelina seeds contain more than 40–50% of oil and 25–32% of crude protein. Unsaturated fatty acids with several double bonds predominate in redhead oil. Due to this, the oil has a rather low pour point—about mines 18 °C, which will subsequently provide satisfactory low temperature properties of biofuels.

One of the main advantages of Camelina oil is that the process of growing it does not require much cost, which is reflected in the cost of the oil.

In order to substantiate the expediency of growing Camelina oil as an alternative raw material for the production of biodiesel, a comparative analysis of the basic agrotechnical characteristics of the Camelina and rapeseed crops was conducted. The results of the analysis are shown in Table 3.

After analyzing data in Table 3, it can be concluded that Camelina has more potential than rapeseed, primarily due to its resistance to adverse soil and climatic conditions. As a result, it can be grown on low quality soils that are not suitable for other crops.

In addition, the cultivation of Camelina is environmentally safe, because Camelina is characterized by extreme plasticity to agro-ecological conditions of cultivation, does not require the use of fertilizers, pesticides and fungicides [13].

Table 3 Comparative characteristics of Rapeseed and Camelina cultures

Properties	Camelina	Rapeseed
General characteristic	One-year culture	One-year culture
Dry-resistance	Low water requirement	High water demand
Germination potential	Almost all types of soil are suitable	Demanding to the soil
The threat of declining soil fertility	Used as an intermediate crop, after which other crops can be planted	Depletes soils. It is possible to grow rapeseed in the same place only in 3–4 years
The presence of weeds	Isolated essential oil that inhibits the growth and development of weeds from the stage of stem formation to the full maturity of the seeds	A lot of weeds
Seed loss	High resistance to cracking	Low resistance to cracking
Vulnerability of crops by pests	Pests and diseases are not Detected	Strongly affected by pests
Vegetation period	60–75 days	90–100 days

From [1, 2], it is known that in Ukraine, nowadays, the sown area of Camelina occupies 5–6 thousand hectares (3% of all oilseeds), mainly in the northern part of the left bank of the Forest-Steppe. It is also noted that these areas can be increased by 3–4 times. However, to date, there is no clear strategy in Ukraine to develop Camelina cultivation [4].

Instead, in the US, Canada, some EU countries are considered to be one of the most promising oilseeds for biofuels production. It has been shown that until recently rapeseed was the main raw material for the production of alternative motor fuels (the so-called "first generation" biofuels). However, due to a number of difficulties and ambiguous issues related to rapeseed cultivation, the situation has changed significantly over the last 5 years. The reason for this is the considerable resource and energy costs of the rapeseed cultivation process. This is due to the fact that obtaining high rape crops requires intensive cultivation of fertile land, which quickly depletes them, the introduction of large quantities of fertilizers and pest control substances. Rape is very demanding on climatic and soil conditions. In addition, the problem is that rapeseed production on fertile land is a competition for food products. In this regard, further research into the use of rapeseed to produce biofuels, including aviation, is not appropriate.

An alternative solution to the problem is to use renewable plant material that does not compete with the food industry and does not present a short or long-term threat to the environment, i.e. the receipt and use of which is sustainable. This view is expressed by scientists in, calling alternative fuels on the basis of renewable raw materials second-generation biofuels. One of these types of raw materials, in particular, is Camelina oil.

A successful experience of using Camelina oil to produce aviation biofuels is described. Thus, flight tests were successfully carried out on airplanes of various types using mixtures of traditional fuel for jet engines of petroleum origin and products of processing of red oil. The latter were a mixture of aromatic hydrocarbons and C_7–C_9 isoalkanes, which were obtained by hydrodeoxygenation of oil, followed by selective cracking of the formed linear alkanes and isomerization and aromatization of the products of cracking. However, the main disadvantage of such biofuels is that, in chemical composition, they are a mixture of carbon-hydrogen, similar to petroleum jet fuels.

Another solution to the above problem is the potential for the introduction of fatty acid alkyl esters into the propellant composition. From works it is known that their production is based on the simplest chemical and technological point of view of the process of transformation of triglycerides—alcoholysis (esterification) with monohydric alcohols.

5 Conclusions

In view of the above, it is quite obvious that growing Camelina as a raw material for biofuel production will have some advantages over other crops used today. The use of biofuels based on Camelina oil will reduce CO_2 emissions throughout the lifecycle of such fuels, reduce the anthropogenic load on the environment and expand the raw material base for the production of motor fuels. This will reduce energy dependence on non-renewable energy sources.

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