# BIODIZEL KAO ALTERNATIVNO MOTORNO GORIVO
# BIODIESEL AS ALTERNATIVE ENGINE FUEL

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Gotovo sve zemlje Europske unije, a i većina zemalja u tranziciji u posljednjem su desetljeću, a neke i ranije, pokrenule proizvodnju biogoriva i to biodizelskoga goriva i etanola. Na temelju pregleda brojnih rezultata istraživanja u svijetu, u ovom se radu analiziraju najvažnija svojstva biodizelskoga goriva, njegova dosadašnja primjena kao alternativnog goriva za dizel motore, te utjecaj njegova sagorijevanja na okoliš u odnosu na mineralno dizel gorivo. Kako je osnovna sirovina za proizvodnju biodizela iz obnovljivih resursa ulje uljane repice, detaljno se analizira postojeća struktura sjetve i udio uljane repice na obradivim površinama u Hrvatskoj, te realne mogućnosti proizvodnje ove kulture za neprehrambeni lanac, odnosno mogućnosti proizvodnje biodizela u Hrvatskoj.

Practically all the countries in the European Union and most of the transition countries have in the last decade, and some even earlier than that, started off the production of biofuels, that is, of biodiesel fuel and ethanol. On the basis of a survey of numerous results of investigations in the world, in this work the most important properties of biodiesel fuel are reviewed, its employment to date as alternative fuel for diesel engines, and the environmental impact of its combustion as compared with that of mineral diesel fuel. Since the basic raw material for the production of biodiesel from renewable resources is the oil of oilseed rape, a detailed analysis is given of the existing structure of the crop and the percentage of the cultivable land in Croatia given over to oilseed rape, as well as the realistic opportunities for the production of this crop for the non-food chain, in other words, the opportunity for the production of biodiesel in Croatia.

Ključne riječi: biljno ulje, biodizel, sačma, transesterifikacija, uljana repica
Key words: biodiesel, cake, oilseed rape, plant oil, transesterification


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FUEL

# 1 UVOD

Gotovo sve zemlje Europske unije, a i većina zemalja u tranziciji u posljednjem su desetljeću, a neke i ranije, pokrenule proizvodnju biogoriva i to biodizelskoga goriva i etanola. Takav trend nastavit će se i u budućnosti što pokazuje i Direktiva Europske unije (2003/30/EC) o alternativnim gorivima u cestovnom prijevozu te mjerama za promociju biogoriva [1]. U navedenom se dokumentu predlažu sljedeće mjere:

- do 2020. treba 20 % tradicionalnih goriva u prometu zamijeniti alternativnim,
- zemlje članice Europske unije imaju pravo primjenjivati diferenciranu poreznu stopu na biogoriva, kako bi se potaknulo njihovo korištenje,
- do 2005. udio biogoriva u Europskoj uniji trebao je iznositi minimalno 2 %. Nakon toga udio u svakoj zemlji članici morat će iznositi:

| 2006. | 2007. | 2008. | 2009. | 2010. |
|---|---|---|---|---|
| 2,75 % | 3,5 % | 4,25 % | 5 % | 5,75 % . |

Navedeni zahtjevi su obvezujući, što znači da se prije navedena zamjena mora izvršiti. Sve su ih članice Europske unije prihvatile uz dinamiku primjerenu svojim mogućnostima, ali ih moraju prihvatiti i buduće članice, što znači da navedene obveze mora prihvatiti i Republika Hrvatska, kao jedna od budućih članica Europske unije.

# 1 INTRODUCTION

Practically all the countries in the European Union and most of the transition countries have in the last decade, and some even earlier than that, started off the production of biofuels, that is, of biodiesel fuel and ethanol. Such a trend will be continued in future as well, as shown by the European Union Directive (2003/30/EC) concerning alternative fuels in road transportation and measures for the promotion of biofuels [1]. This document proposes the following measures:

- up to the year 2020, 20 % of the traditional fuels in transportation will have to be replaced with alternative fuels,
- European Union member countries have the right to apply differential tax rates to biofuels in order to foster their use,
- by 2005 biofuels must account for a minimum of 2 % of European Union fuel use. After that the percentage in each member country will have to come to:

| 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| 2,75 % | 3,5 % | 4,25 % | 5 % | 5,75 % . |

These requests are binding, which means that the substitution mentioned above must be carried out. All the members of the European Union have accepted them, along with dynamics appropriate to their own capacities, but they also have to be accepted by future members, which means that the Republic of Croatia also has to accept these obligations, as one of the future member of the European Union.

Tablica 1 – Procjene proizvodnje biodizela i kapaciteta za proizvodnju u EU 25 2004. i 2005. [2]
Table 1 – Estimates of the production of biodiesel and production capacities in the EU 25 in 2004 and 2005 [2]

| Zemlja / Country | Proizvodnja / Production 2004. ($10^3$ t) | Proizvodnja / Production 2005. ($10^3$ t) | Kapaciteti / Capacities 2004. ($10^3$ t) | Kapaciteti / Capacities 2005. ($10^3$ t) |
|---|---|---|---|---|
| Njemačka / Germany | 1 035 | 1 669 | 1 903 | 2 681 |
| Francuska / France | 348 | 492 | 532 | 775 |
| Italija / Italy | 320 | 396 | 827 | 857 |
| Češka / Czech Republic | 60 | 133 | 188 | 203 |
| Poljska / Poland | 0 | 100 | 100 | 150 |
| Austrija / Austria | 57 | 85 | 125 | 134 |
| Slovačka / Slovakia | 15 | 78 | 89 | 89 |
| Španjolska / Spain | 13 | 73 | 100 | 224 |
| Danska / Denmark | 70 | 71 | 81 | 81 |
| Velika Britanija / UK | 9 | 51 | 129 | 445 |
| Slovenija / Slovenia | 0 | 8 | 17 | 17 |
| Estonija / Estonia | 0 | 7 | 10 | 20 |
| Letonija / Latvia | 5 | 7 | 10 | 10 |
| Litva / Lithuania | 0 | 5 | 5 | 8 |
| Grčka / Greece | 0 | 3 | 35 | 75 |
| Malta / Malta | 0 | 2 | 2 | 3 |
| Belgija / Belgium | 0 | 1 | 55 | 85 |
| Cipar / Cyprus | 0 | 1 | 2 | 2 |
| Portugal / Portugal | 0 | 1 | 6 | 146 |
| Švedska / Sweden | 1,4 | 1 | 12 | 52 |
| Ukupno / Total | 1 933,4 | 3 184 | 4 228 | 6 069 |

Prema podacima European Biodiesel Board (tablica 1) ukupna proizvodnja biodizela u EU 25 je porasla sa 1,9 milijuna tona u 2004. na blizu 3,2 milijuna tona u 2005. ili za 65 %. Broj zemalja s industrijom biodizela se gotovo udvostručio u 2005. [3] u odnosu na 2004. [4]. Proporcionalno su tome rasli i kapaciteti za proizvodnju biodizela te su u 2006. iznosili više od 6 milijuna tona, što će omogućiti daljnju ekspanziju industrije biodizela u Europskoj uniji. Kako biodizel čini oko 80 % biogoriva u Europskoj uniji – ostalo je bioetanol – ovi podaci potvrđuju činjenicu da globalni cilj od 2 % biogoriva u 2005. godini postavljen u Direktivi Europske unije 2003/30/EC još nije dostignut. Ako se uzme samo tržište dizela u Europskoj uniji, proizvodnja biodizela je uz postojeći trend porasta blizu očekivanog cilja od 2 %. Danas tržišni udio biodizela iznosi približno 1,5 % od tržišta konvencionalnog dizelskog goriva u Europskoj uniji.

According to European Biodiesel Board figures (Table 1) the total production of biodiesel in the EU 25 rose from 1,9 million tons in 2004 to close on 3,2 million tons in 2005, that is, by 65 %. The number of countries with a biodiesel industry almost doubled in 2005 [3] over 2004 [4]. Capacities for the production of biodiesel have also risen proportionally and in 2006 came to more than 6 million tons, which will enable further expansion of the biodiesel industry in the European Union. Since biodiesel comprises about 80 % of the biofuel in the European Union – the rest is accounted for by ethanol – these figures confirm the fact that the global objective of 2 % biofuels in 2005 established in European Union Directive 2003/30/EC has not yet been attained. If only the diesel market in the European Union is taken, the production of biodiesel given the existing trend of growth is close to the expected target of 2 %. Today the market share of biodiesel comes to about 1,5 % of the market for conventional diesel in the European Union.

U budućem korištenju biogoriva u Europskoj uniji podjednaku će ulogu imati i biodizelsko gorivo i bioetanol, pri čemu će za njihovu proizvodnju biti angažirano više milijuna hektara poljoprivrednih površina i to prema scenariju prikazanom u tablici 2 [5].

In future use of biofuel in European Union, biodiesel and bioethanol will have equal roles, with over a several million hectares of agricultural land earmarked for their production, according to the scenario presented in Table 2 [5].

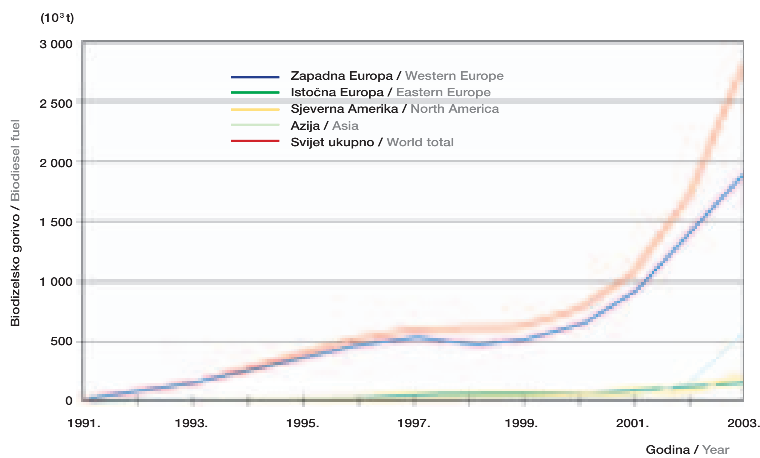
Tablica 2 – Poljoprivredne površine predviđene za proizvodnju biogoriva u Europskoj uniji u budućnosti
Table 2 – Agricultural land envisaged for the production of biofuel in the European Union in future

| Ukupne površine za biogoriva / Total land area for biofuels ($10^6$ ha) | Površine za biodizelsko gorivo / Land for biodiesel ($10^6$ ha) | Površine za bioetanol / Land for bioethanol ($10^6$ ha) |
|---|---|---|
| 20 | 10 | 10 |

Konačno, može se zaključiti da je biodizelsko gorivo široko prihvaćeni obnovljivi izvor energije, o čemu osim svega navedenog svjedoče i podaci o rastu proizvodnje istog u svijetu do 2003. godine (slika 1).

Finally, it can be concluded that biodiesel fuel is a widely accepted renewable source of energy, as indicated, apart from the facts stated above, by the data concerning the growth in production of this fuel in the world up to 2003 (Figure 1).

**Slika 1**
Svjetska proizvodnja biodizelskoga goriva [6]
**Figure 1**
World production of biodiesel fuel [6]




Poseban naglasak u procesu proizvodnje biodizelskoga goriva u svijetu dan je na korištenju svih nusproizvoda. Uporaba pogače i sačme u ishrani stoke danas je sve veća zbog pojave bolesti Bovina spongiformna encefalopatija (kravlje ludilo), koja se prenosi hranom za stoku animalnog podrijetla. Zbog sve većih zahtjeva prema poljoprivredi, vezanih za proizvodnju ekološki ispravne hrane, upravo su pogača i sačma zbog svojih energetsko-nutritivnih vrijednosti uspješno zamijenile spornu komponentu animalnog podrijetla u hrani za stoku. Sve veće cijene pogača i sačme omogućile su da njihov plasman uopće nije upitan. Dapače, upravo je njihova proizvodnja u nekim postrojenjima za proizvodnju biodizelskoga goriva u Europskoj uniji postala primarni proizvod, koji uspješno pridonosi pozitivnoj ekonomskoj bilanci proizvodnje [6].

A special emphasis is placed in the process of the production of biodiesel in the world on the use of all the by-products. The use of the cake and meal in fodder is increasingly important because of the appearance of the disease bovine spongiform encephalitis (mad cow disease) which is transmitted with fodder of animal origin. Because of the ever greater demands made on agriculture related to the production of ecologically acceptable food, the cake and meal, because of their energy and nutritive values, have successfully replaced the disputable component of animal origin in fodder. The increasingly high prices of cake and meal have enabled their sales to be not at all a matter of doubt. Indeed, in some of the biodiesel fuel plants in European Union they have become the primary products, which have successfully contributed to the achievement of a positive economic balance for this production [6]

## 2 SVOJSTVA BIODIZELSKOGA GORIVA

Prednost biodizelskoga goriva u odnosu na mineralno dizelsko gorivo, s ekološkog stajališta, proizlazi iz povoljnije bilance ugljikovog dioksida. Osnova za proizvodnju biodizelskoga goriva jest sjeme, odnosno ulje neke uljane kulture, a poznato je da biljka za svoj rast troši određenu količinu ugljikovog dioksida. Pri uzgoju tih kultura koriste se razni poljoprivredni strojevi koji svojim radom proizvode ugljikov dioksid, a isti nastaje i u procesu prerade ulja u biodizelsko gorivo. Slična je situacija i s proizvodnjom mineralnoga dizela. Međutim, razlika je u tome što se za daljnji uzgoj uljane repice iz atmosfere preuzima dio ugljikovog dioksida nastalog izgaranjem i proizvodnjom biodizelskoga goriva, dok se kod mineralnoga dizelskoga goriva nastali ugljikov dioksid neprestano akumulira u atmosferi. Uzgojem uljane repice, proizvodnjom ekološki ispravnoga goriva, njegovim izgaranjem te ponovnim uzgojem, stvara se djelomično zatvoren i ekološki povoljan lanac nastajanja i potrošnje ugljikovog dioksida [7] i [8].

Pri razmatranju bilance ugljikovog dioksida nastalog izgaranjem u motoru i proizvodnje biodizelskoga goriva s jedne strane i mineralnoga goriva s druge strane, procjenjuje se da je produkcija ugljikovog dioksida biodizelskoga goriva na razini od 40 do 50 % produkcije ugljikovog dioksida pri proizvodnji i izgaranju mineralnoga dizelskoga goriva [9].

U literaturi se nalaze podaci prema kojima se emisija ugljikovog dioksida nastalog izgaranjem biodizelskoga goriva kreće u rasponu od 20 % do 25 % emisije ugljikovog dioksida nastalog izgaranjem mineralnoga dizelskoga goriva, a neki autori čak navode da se sav ugljikov dioksid nastao proizvodnjom i izgaranjem biodizelskoga goriva ponovno apsorbira iz atmosfere od strane biljaka, što je moguće samo pri uporabi sirovoga repičinog ulja kao goriva, što nije slučaj s biodizelskim gorivom [10]. Ukupna bilanca stakleničnih plinova pokazuje da se izgaranjem i proizvodnjom 1 kg mineralnoga dizela emitira 4,01 kg $CO_{2ekv}$, dok se proizvodnjom i korištenjem biodizelskoga goriva i njegovih nusproizvoda emitira [11]:

- 0,916 kg $CO_{2ekv}$/kg biodizela,
- 0,314 kg $CO_{2ekv}$/kg ostatka repice (stočna hrana),
- 0,420 kg $CO_{2ekv}$/kg glicerola.

Jedno od najvažnijih svojstava dizelskoga goriva je njegova sposobnost samozapaljenja, svojstvo koje definira cetanski broj, i što je on veći to se

## 2 THE PROPERTIES OF BIODIESEL FUEL

The advantages of biodiesel fuel as compared with mineral diesel fuel derives, from the ecological point of view, is in a more favourable carbon dioxide balance. The basis for the production of biodiesel fuel is seed, that is, the oil of certain oil crops, and it is well known that a plant, for its growth, has to make use of a certain amount of carbon dioxide. In the cultivation of these crops, various farm machines are used that produce carbon dioxide in their work, and the same thing happens in the process of converting oil into biodiesel fuel. A similar situation applies with the production of mineral diesel oil. However, the difference lies in the fact that for the further cultivation of oilseed rape some of the carbon dioxide created by the combustion and production of biodiesel fuel is taken from the atmosphere, while with the use of mineral diesel fuel, the carbon dioxide produced incessantly goes on accumulating in the atmosphere. Through the cultivation of oilseed rape, with the production of ecologically acceptable fuel, through its combustion and re-cultivation, a partially closed and ecologically favourable chain of the generation and consumption of carbon dioxide is thus created [7] and [8].

In the consideration of the balance of carbon dioxide created by combustion in an engine and in the production of biodiesel fuel on the one hand and of mineral fuel on the other, it is estimated that the production of carbon dioxide of biodiesel fuel is at the level of 40 to 50% of the production of carbon dioxide during the production and combustion of mineral diesel fuel [9].

Data can be found in the literature according to which the emission of carbon dioxide created by the combustion of biodiesel fuel ranges between 20 to 25 % of the emission of carbon dioxide from the combustion of mineral diesel fuel, and some authors go as far as to say that all the carbon dioxide created by the production and combustion of biodiesel fuel is reabsorbed from the atmosphere by the plants, which is possible only in the use of raw rapeseed oil as fuel, but is not the case with biodiesel fuel [10]. The overall balance of greenhouse gases shows that with the combustion and production of 1 kg of mineral diesel fuel 4,01 kg $CO_{2ekv}$ is emitted, while with the production and use of biodiesel fuel and its by-products the following are emitted [11]:

- 0,916 kg $CO_{2ekv}$/kg biodiesel,
- 0,314 kg $CO_{2ekv}$/kg rapeseed residue (fodder),
- 0,420 kg $CO_{2ekv}$/kg glycerol.

gorivo brže zapali. Istraživanja su pokazala da je prosječan cetanski broj biodizelskoga goriva 48 u usporedbi s cetanskim brojem mineralnog dizela koji iznosi 50.

Mazivost, još jedno važno svojstvo dizelskoga goriva, definira njegova maziva svojstva. Biodizelsko gorivo ima bolju mazivost od mineralnog dizelskoga goriva s niskom koncentracijom sumpora od 500 ppm.

Od ukupne mase B100 (100 % biodizelsko gorivo), 11 % te mase jest kisik. Prisustvo kisika u biodizelskom gorivu poboljšava njegovo izgaranje, čime se smanjuje količina ugljikovog dioksida, CO i emisija krutih čestica. Međutim, oksigenirana goriva mogu povećati emisiju dušikovih oksida. Testovi na motorima potvrdili su ta očekivana povećanja, ali i smanjenja ispušnih plinova i krutih tvari iz motora.

Biodizelsko gorivo ima i određenih nedostatka. Svojstva biodizelskoga goriva u hladnim uvjetima lošija su od svojstava dizelskoga goriva. Pri niskim temperaturama, biodizelsko gorivo formira kristale voska, koji mogu dovesti do začepljenja u sustavu motora. Pri još nižim temperaturama, biodizelsko gorivo dobiva svojstva gela što znači da se isto ne može crpsti iz spremnika. U vozilima koja se pogone mješavinom biodizelskoga goriva i mineralnoga dizelskoga goriva nastaju problemi s opskrbom motora gorivom pri manje negativnim temperaturama nego kod onih vozila koja se pogone dizelskim gorivom. Zbog toga je potrebno biodizelsko gorivo dodatno aditirati, čime bi njegova uporaba bila moguća i pri niskim temperaturama.

Biodizelsko gorivo kod automobila starijih godišta djeluje poput otapala i može uzrokovati otapanje boje. Biodizelsko gorivo također kod automobila starijih godišta agresivno djeluje na brtvila u motorima. To znači da je brtvila potrebno zamijeniti ako se u takvim automobilima želi koristiti kao pogonsko gorivo biodizelsko gorivo.

Uporaba B20 (mješavina 20 % biodizelskoga goriva i 80 % mineralnog dizela) i B100 u bilo kojem vozilu zahtijeva određeni oprez. Zbog loše kakvoće dizelskoga goriva izgaranjem u motoru stvaraju se naslage. One, uporabom biodizelskoga goriva mogu promijeniti konzistenciju, te zbog toga može doći do njihove migracije i začepljivanja filtara čija je zadaća pročišćavanje pogonskog goriva. Zato je potrebno nakon izvjesnog vremena po prelasku na biodizelsko gorivo obaviti servis.

Biodizelsko gorivo ima nešto veću potrošnju u odnosu na potrošnju mineralnoga dizelskoga goriva pri istom broju prijeđenih kilometara. Ako se promatra energetska iskoristivost motora, a to

One of the most important properties of diesel fuel is its capability for self-ignition, a property that is defined by the cetane number, and the greater this is, the faster the fuel ignites. Research has shown that the average cetane number of biodiesel is 48, as compared with the cetane number of mineral diesel, which is 50.

Lubricity, another important property of diesel oil, defines its lubricative characteristics. Biodiesel fuel has better lubricity than mineral diesel fuel with a low sulphur concentration of 500 ppm.

Of the total mass of B100 (100 % biodiesel fuel), 11 % is oxygen. The presence of oxygen in biodiesel fuel improves its combustion, thus reducing the quantity of carbon dioxide, CO and the emission of solid particles. However, oxygenated fuels can increase the emission of nitrogen oxides. Engine tests have confirmed this expected increase, as well as the reduction of exhaust gases and solid matter from engines.

Biodiesel also has certain drawbacks. The properties of biodiesel fuels in cold conditions are poorer than those of fossil diesel. At low temperatures, biodiesel fuel forms wax crystals, which can lead to blockage in the engine. At still lower temperatures, biodiesel fuel takes on the properties of a gel, which means that it cannot be pumped from the fuel tank. In vehicles driven by a mixture of biodiesel and fossil diesel, problems arise with the fuel supply to the motor at less negative temperatures than in those vehicles that are driven with fossil diesel alone. Because of this reason biodiesel has to be supplemented with additives to make it usable at low temperatures.

In automobiles made some time ago, biodiesel fuel acts as a solvent and can dissolve the paint. Biodiesel fuel, also with cars of older years of production, acts aggressively against the gaskets. This means that gaskets must be changed if it is wished to use biodiesel fuel as the drive fuel in these vehicles.

The use of B20 (a mixture of 20 % biodiesel fuel and 80 % fossil diesel) and B100 in any vehicle at all requires a certain amount of caution. Because of poor quality diesel fuel, deposits are created in the engine on combustion. With the use of biodiesel, these deposits can change their consistence, and because of this they can migrate and block the filters the function of which is to refine the drive fuel. For this reason it is necessary a certain time after changing over to biodiesel fuel to have a service done.

Consumption of biodiesel is slightly higher than that of fossil diesel fuel for the same mileage. If the energy use of the engine is considered, that is je postotak toplinske energije goriva koju oslobađa motor, biodizelsko gorivo nije pokazalo signifikantan učinak na energetsku iskoristivost niti jednog istraživanog motora. Za razliku od energetske, volumetrijska iskoristivost koja se uglavnom izražava kao kilometri po litri goriva pokazala je da udio energije po litri biodizelskoga goriva iznosi otprilike 11 % manje nego kod dizelskoga goriva. Nadalje, očekuje se da će vozila koja koriste B20 postizati 2,2 % manje kilometara po litri goriva. Međutim, taj nedostatak kompenzira se udjelom kisika u biodizelskom gorivu.

U tablici 3 prikazane su za izgaranje najvažnije značajke standardnoga dizelskoga goriva i metilnog estera ulja uljane repice – biodizela [12].

the percentage of thermal energy of the fuel that is released by the engine, biodiesel did not show a significant effect on the energy use of a single engine investigated. Unlike the energy, the volumetric use which is on the whole expressed as kilometres driven per litre of fuel, it was shown that the energy share per litre of biodiesel fuel comes to about 11 % less than with fossil diesel fuel. Further, it is expected that vehicles that use B20 will attain 2,2 % fewer miles per litre of fuel. However, this drawback is compensated for by the proportion of oxygen in biodiesel fuel.

Table 3 shows the properties of standard diesel fuel and the methyl ester of rapeseed oil – biodiesel that are most important for combustion [12].

Tablica 3 – Značajke mineralnoga dizelskoga goriva i metilnog estera ulja uljane repice
Table 3 – Properties of fossil diesel oil and of the methyl ester of rapeseed oil

| Značajke / Properties | Jedinica / Unit | Mineralni dizel / Fossil diesel | RME* |
|---|---|---|---|
| Približna kemijska formula / Approximate chemical formula | | $CH_{1,85}$ | $C_{19}H_{35,2}O_2$ |
| Molekularna masa / Molecular mass | g/mol | 120–320 | 296 |
| Sadržaj ugljika / Carbon content | % mase / mass | 86,5 | 76,5 |
| Sadržaj vodika / Hydrogen content | % mase / mass | 13 | 12,3 |
| Sadržaj kisika / Oxygen content | % mase / mass | 0 | 11,0 |
| Sadržaj sumpora / Sulphur content | % mase / mass | 0,14 | 0,002 |
| Sadržaj dušika / Nitrogen content | % mase / mass | 0,015 | 0,1 |
| Sadržaj pepela / Ash content | % mase / mass | 0,01 | 0,02 |
| Stehiometrijska količina zraka / Stoichiometric quantity of air | kg zraka/kg goriva / kg air/kg fuel | 14,4 | 12,8 |
| Gustoća / Density (15 °C) | kg/m³ | 835 | 878 |
| Promjena gustoće / Density change | kg/m³K | 0,73 | 0,83 |
| Ogrjevna vrijednost / Thermal value | MJ/kg | 42,50 | 37,10 |
| Početak isparivanja / Start of evaporation | °C | ~ 180 | ~ 320 |
| Kraj isparavanja / End of evaporation | °C | ~ 350 | ~ 360 |
| Cetanski broj / Cetane number | | 50 | ~ 48 |
| Kinematička viskoznost / Kinematic viscosity (20 °C) | mm²/s | 6,65 | 7,07 |
| Kinematička viskoznost / Kinematic viscosity (40 °C) | mm²/s | 2,31 | 4,35 |
| Kinematička viskoznost / Kinematic viscosity (100 °C) | mm²/s | 0,8 | 1,78 |
| Temperatura stinjavanja / Gel temperature | °C | –24 | –12 |
| Plamište / Ignition point | °C | 70–90 | 110–140 |

* Metilni ester ulja uljane repice / Methyl ester of rapeseed oil (Rapeseed methyl ester)

Početne teškoće u primjeni biodizelskoga goriva s početka desetljeća u međuvremenu su prevladane te svi današnji dizelski motori mogu rabiti biodizelsko gorivo bez ikakve opasnosti za sam motor ili prateće uređaje [13].

Initial difficulties in the application of biodiesel from the beginning of the decade have been overcome in the meantime and all current diesel engines can use biodiesel fuel without any danger to the engine itself or to ancillary equipment [13].

## 2.1 Biorazgradivost biodizelskoga goriva

U proteklim se godinama zakonskim regulativama u većini država nastoji smanjiti udio sumpora i aromata u mineralnim dizelskim gorivima radi poboljšavanja kakvoće zraka. Nažalost, u procesu odstranjivanja sumpora i aromata te ostalih komponenata (poliaromata i dušičnih komponenata) izdvajaju se i komponente koje imaju zadaću podmazivanja u motoru. To rezultira smanjenom sposobnošću podmazivanja nisko-sumpornih mineralnih goriva, koja se na neki način mora nadomjestiti. Rješenje se našlo u dobrim mazivim svojstvima biodizelskoga goriva. Samo 0,4 % biodizelskoga goriva u mineralnom dizelu omogućava minimum potrebne mazivosti koju zahtijeva standard za mineralno dizelsko gorivo. Maksimalna mazivost postiže se mješavinama približno 10 % biodizelskoga u mineralno dizelsko gorivo [11].

Biorazgradivost biodizelskoga goriva može se uvidjeti kroz podatke o COD (kemijska potrošnja kisika), $BOD_5$ (biokemijska potrošnja kisika), biorazgradivost u vodenim otopinama i biorazgradivost u tlu. Općenito, metilni i etilni esteri imaju visoke COD i $BOD_5$ vrijednosti, što je poželjno kada se radi o biorazgradnji, jer to znači da se materijal vrlo brzo razgrađuje. Istraživanjem COD vrijednosti, utvrđeno je da ona nije bila značajno različita između RME (metilni ester ulja uljane repice), REE (etilni ester ulja uljane repice) i 2-D (Phillips 2-D diesel). Suprotno tomu, $BOD_5$ vrijednosti za RME i REE bile su dvostruko veće od $BOD_5$ vrijednosti za 2-D. Signifikantno manja ($p<0,01$) $BOD_5$ vrijednost kod 2-D upućuje na prisustvo mnogo manje količine mikrobno biorazgradive organske tvari u tome gorivu. Manja $BOD_5$ vrijednost 2-D također bi se mogla odraziti na mikrobnu toksičnost dizelskoga goriva ili njegovih komponenti.

Sva biodizelska goriva su dobro razgradiva u vodi i tlu. Istraživanja su pokazala da se u razdoblju od 28 dana biodizelsko gorivo u vodi razgradilo 84 %, a u tlu 88 %, što su gotovo dvostruko veće vrijednosti u odnosu na dizelsko gorivo. Rezultati također upućuju da je povećanje koncentracije REE u mješavinama uzrokovalo linearno povećanje vrijednosti ukupne biorazgradnje. Nakon 4 do 6 tjedana od ulaska biodizelskoga goriva u tlo biljke su normalno klijale i rasle.

## 2.2 Toksičnost biodizelskoga goriva

Testovi toksičnosti pokazali su da je biodizelsko gorivo značajno manje toksično od dizelskoga goriva, ali su potrebne određene mjere opreza kod rukovanja njime. Iako su zabilježeni neki negativni učinci na testovima sa zečevima i štakorima,

## 2.1 Biodegradability of biodiesel fuel

In recent years, statutory regulations in most countries have endeavoured to reduce the proportions of sulphur and aromatics in fossil diesel fuels for the sake of air quality improvement. Unfortunately, in the process of removing sulphur and aromatic and other components (polyaromatics and nitrogen components) components that have a lubrication function in the engine have also been removed. This has resulted in decreased lubrication capacity in low sulphur fossil fuels, which has to be replaced in some manner. A solution was found in the good lubricating qualities of biodiesel fuel. Only 0,4 % of biodiesel in fossil diesel enables the minimum necessary lubrication required by fossil diesel fuel standards. Maximum lubrication is achieved with a mixture of about 10 % biodiesel in fossil diesel fuel [11].

The biodegradability of biodiesel fuel can be seen through the COD data (chemical oxygen demand), $BOD_5$ (biochemical oxygen demand), biodegradability in aqueous solutions and biodegradability in soil. In general methyl and ethyl esters have high COD and $BOD_5$ values, which is desirable where biodegradability is concerned, for it means that the material is degraded very rapidly. COD value research has shown that there was no significant difference with respect to this among RME (rapeseed methyl ester), REE (rapeseed ethyl ester) and 2-D (Phillips 2-D diesel). As against this the $BOD_5$ values of RME and REE were twice as great as that of 2-D. A significantly lower ($p<0.01$) $BOD_5$ value in 2-D indicates the presence of far fewer amounts of microbially biodegradable organic substances in this fuel. The lower $BOD_5$, value of 2-D might also be reflected on the microbial toxicity of diesel fuel or components of the fuel.

All biodiesel fuels are satisfactorily degradable in water and soil. Research has shown that in a period of 28 days biodiesel fuel degrades 84 % in water and 88 % in the soil, which is almost twice the value of fossil diesel. These results also indicate that an increase in the concentration of REE in mixtures caused a linear increase in the value of total biodegradability. After 4 to 6 weeks from entry of biodiesel into the soil, plants normally germinated and grew.

## 2.2 Toxicity of biodiesel fuel

Toxicity tests have shown that biodiesel fuel is significantly less toxic than fossil diesel, but certain safety measures are required in handling it. Although some negative effects have been shown on tests with rabbits and rats, no animal has died as a result of contact with biodiesel or fossil diesel fuel. Animals that were in contact with fossil diesel nijedna životinja nije uginula zbog kontakta s biodizelskim ili dizelskim gorivom. Životinje koje su bile u dodiru s dizelskim gorivom imale su lošiju kliničku sliku. Oralna $LD_{50}$ vrijednost (letalna doza za 50 % populacije) svake istraživane tvari (REE, RME, 2-D) veća je od 5000 mg/kg, što je granična doza. Doza od 2000 mg/kg pokazala se kao NOAEL (No Observed Adverse Effect Level), dakle kao doza kod koje nisu zamijećene promjene. Praćenjem akutne oralne toksičnosti, 100 % RME se pokazao najmanje opasnim, dok je kod akutne dermalne toksičnosti najmanje opasan bio 100 % REE.

Istraživanje toksičnosti na vodenom organizmu Daphnia Magna koji je osjetljiv na naftne mrlje te referentan za navedena istraživanja pokazalo je da je dizelsko gorivo 2,6 puta toksičnije od NaCl, dok je biodizelsko bilo manje toksično od NaCl [14].

### 2.3 Utjecaj izgaranja biodizelskoga goriva na okoliš

Jedno od najvažnijih svojstava biodizelskoga goriva kao pogonskog goriva je smanjena emisija štetnih ispušnih plinova za više od 50 % u odnosu na dizelsko gorivo te činjenica da ono gotovo nema sumpora, fosfora i olova, pri čemu je količina čađi u ispušnim plinovima smanjena za oko 50 % u odnosu na dizelsko gorivo. Dakle, biodizelsko gorivo u odnosu na dizelsko ima značajno niži stupanj onečišćenja okoliša pri eksploataciji, što je od velike važnosti napose za gradove i velegradove u kojima se gradski prijevoz odvija njegovom uporabom.

Korisnici goriva su zapazili da ispušni plinovi koji nastaju prilikom izgaranja biodizelskoga goriva nemaju neugodan miris, za razliku od ispušnih plinova koji nastaju izgaranjem mineralnoga dizelskoga goriva.

Američki Nacionalni laboratorij za obnovljivu energiju (National Renewable Energy Laboratory, NREL) radi na istraživanjima emisije dušikovih oksida iz biodizelskoga goriva. Istraživanja koja provodi ovaj laboratorij idu u smjeru pronalaženja određenog omjera biodizelskoga goriva i drugih spojeva kojim se neće povećavati emisija dušikovih oksida.

Emisiju dušikovih oksida iz biodizelskoga goriva moguće je smanjiti miješanjem s kerozinom. Procjenjuje se da bi mješavina kerozina i biodizelskoga goriva u omjeru 60:40 (60 % kerozina i 40 % biodizelskoga goriva) imala emisiju dušikovih oksida na razini dizelskoga goriva. Dušikovi oksidi i ugljikovodici su preteče ozona. Ugljikov monoksid (CO) također je prekursor ozona, ali od manjeg značenja. Iz tog razloga potrebno je napraviti scenarij o kakvoći zraka, odnosno da li

had bad clinical results. The oral $LD_{50}$ value (a lethal dose for 50 % of the population) for each investigated substance (REE, RME, 2-D) is greater than 5000 mg/kg, which is the borderline dose. A dose of 2000 mg/kg proved to be NOAEL or at the no observed adverse effect level, as a dose, then, at which no changes were noted. When acute oral toxicity was measured, 100 % RME was the least hazardous, while in the case of acute dermal toxicity the least dangerous was 100 % REE.

Investigation of the toxicity to the aquatic organism Daphnia Magna, which is susceptible to oil slicks and a reference for the said research showed that fossil diesel is 2,6 times more toxic than NaCl, while biodiesel was less toxic than NaCl [14].

### 2.3 Biodiesel combustion environmental impact

One of the most important properties of biodiesel fuel as drive fuel is a 50 % reduction in the emission of harmful exhaust gases and the fact that it has practically no sulphur, phosphor and lead, with the quantity of soot in the exhaust gases being cut about 50 %. Thus as against fossil, biodiesel has a significantly lower degree of environmental pollution in use, which is of great importance particularly for cities and conurbations in which city transport is carried out with the use of this fuel.

Users of the fuel have noted that the exhaust gases created during the combustion of biodiesel fuel do not have the unpleasant smell associated with the exhaust gases created by the combustion of fossil diesel fuel.

NREL, the American National Renewable Energy Laboratory is working on research into the emission of nitrogen oxides from biodiesel fuel. The research carried out by this laboratory is aimed at finding a given ratio of biodiesel and other compounds at which the emission of nitrogen oxides will not be increased.

It is possible to reduce the emission of nitrogen oxides from biodiesel by mixing it with kerosene. It is estimated that a mixture of kerosene and biodiesel in a ratio of 60:40 (60 % kerosene and 40 % biodiesel) would have a nitrogen oxide emission at the level of fossil diesel. Nitrogen oxides and carbohydrates are ozone precursors, as is carbon monoxide (CO), but of less importance. For this reason it is necessary to produce an air quality scenario, that is, to find out whether there will be an increase or a reduction in the ozone level if biodiesel fuel is used without additives.

The use of biodiesel fuel in conventional diesel engines has resulted in an important reduction of će doći do povećanja ili smanjenja razine ozona ako se koristi biodizelsko gorivo bez aditiva.

Uporaba biodizelskoga goriva u konvencionalnim dizelskim motorima rezultira značajnim smanjenjem nesagorjelih ugljikovodika, CO i krutih čestica. Emisija dušikovih dioksida je ili blago smanjena ili blago povećana, ovisno o metodi istraživanja. Uporabom biodizelskoga goriva u konvencionalnim dizelskim motorima, smanjuje se količina čestica ugljika (budući da kisik u gorivu omogućuje sagorijevanje do $CO_2$), eliminira se frakcija sumpora (budući da u gorivu nema sumpora), a topiva frakcija vodika ostaje ista ili je malo povećana.

Biodizelsko gorivo je prvo i jedino biogorivo za koje postoje rezultati istraživanja emisije čestica u zrak te potencijalni učinci na zdravlje ljudi, a koje je predočila Američka agencija za zaštitu okoliša (EPA) nakon primjene najstrožih pravila. Kako je već spomenuto, uporabom biodizelskoga goriva količina smoga smanjuje se za oko 50 % u odnosu na dizelsko gorivo. Emisija inhalirajućih čestica, koje predstavljaju rizik za ljudsko zdravlje, smanjena je za oko 40 % u odnosu na emisiju istih tih čestica iz mineralnoga dizela, a emisija ukupnih ugljikovodika je niža za oko 68 %.

Kod uporabe čistog (100 %) biodizelskoga goriva, emisija $NO_x$ je povećana za oko 6 %, no budući da biodizelsko gorivo gotovo i nema sumpora moguća je primjena kontrolnih metoda i postupaka, pri čemu se emisija $NO_x$ iz biodizelskoga goriva u određenim uvjetima može učinkovito nadgledati i smanjiti tijekom korištenja.

### 2.4 Usporedba svojstava izgaranja biodizelskoga goriva sa svojstvima izgaranja mineralnog dizela

Tijekom ciklusa proizvodnje uljane repice i korištenja biodizelskoga goriva proizvodi se približno 80 % manje $CO_2$ i gotovo 100 % manje $SO_2$ u usporedbi s proizvodnjom i uporabom mineralnog dizela. Iz tablice 4 vidljivo je da biodizelsko gorivo ima izrazito poboljšane karakteristike emisija za gotovo sve (regulirane i neregulirane) zagađivače u usporedbi s mineralnim dizelskim gorivom.

Jedino je emisija $NO_x$ u porastu kod biodizelskoga goriva. Koncentracija $NO_x$ povećava se s povećanjem udjela biodizelskoga goriva u mješavini biodizelskoga i mineralnog dizelskog goriva. Do povećanja koncentracije $NO_x$ može doći zbog visokih temperatura u procesu potpunog izgaranja, a zbog kisika u gorivu. Novija istraživanja nagovješćuju da se povećane emisije $NO_x$ mogu smanjiti korištenjem tehnologija prikladnijih proizvodnji biodizelskoga goriva.

uncombusted hydrocarbons, CO and solid particles. The emission of nitrogen dioxides has been slightly reduced or slightly increased, depending on the research methodology. When biodiesel fuel is used in conventional diesel engines, the quantity of carbon particles is reduced (since the oxygen in the fuel enables it to be combusted to $CO_2$), the sulphur fraction is eliminated (since there is no sulphur in this fuel) and the soluble hydrogen fraction remains the same or is slightly elevated.

Biodiesel is the first and only biofuel for which there are results of research into the emission of particles into the air and the potential effects on human health, presented by the American Environmental Protection Agency (EPA) after application of the most stringent rules. As already mentioned, with the use of biodiesel fuel, the amount of smog is reduced by about 50 % as compared with the situation resulting from fossil diesel. The emission of inhalable particles, which are a human health hazard, is reduced by about 40 % as against the emission of the same particles from fossil diesel, and the emission of total hydrocarbons is about 68 % lower.

In the case of the use of pure (100 %) biodiesel fuel, the $NO_x$ emission is increased by about 6 %, but since biodiesel has practically no sulphur, it is possible to employ control methods and procedures, so that the emission of $NO_x$ from biodiesel fuel in certain conditions can be effectively supervised and reduced during use.

### 2.4 Comparison of the combustion properties of biodiesel with those of fossil diesel

During the oilseed rape production and biodiesel use cycle about 80 % less $CO_2$ and practically 100 % less $SO_2$ is produced than in the production and use of fossil diesel. Table 4 reveals that biodiesel has markedly improved emission characteristics for practically all (regulated or non-regulated) contaminants over fossil diesel.

Only the $NO_x$ emission is elevated in the case of biodiesel fuel. The concentration of $NO_x$ is increased with the increase in the proportion of biodiesel in a mixture of biodiesel and fossil diesel. An increase in $NO_x$ concentration can arise because of the high temperatures involved in the process of total combustion, as well as because of the oxygen in the fuel. More recent research suggests that the increased emissions of $NO_x$ can be reduced by using technologies more suitable to the production of biodiesel fuel.

Tablica 4 – Prosječna emisija iz biodizelskoga goriva u usporedbi s konvencionalnim dizelskim gorivom [15]
Table 4 – Average emission of biodiesel as compared with conventional diesel fuel [15]

| Tip emisije / Type of emission | B100 (100 % biodizela / biodiesel) | B20 (20 % biodizela / biodiesel) |
|---|---|---|
| **Regulirano / Regulated** | | |
| Ukupno neizgoreni ugljikovodici / Total uncombusted hydrocarbons | – 67 % | – 20 % |
| CO | – 48 % | – 12 % |
| Čestice / Particles | – 47 % | – 12 % |
| $NO_x$ | +10 % | +2 % |
| **Neregulirano / Unregulated** | | |
| Sulfati / Sulphates | – 100 % | – 20 %* |
| PAH (policiklički aromatski ugljikovodici) / PAH (polycyclical aromatic hydrocarbons)* | – 80 % | – 13 % |
| nPAH (nitrirani PAH) / (nitrated PAH) ** | – 90 % | – 50 % |
| Mogućnost formiranja smoga / Smog formation | – 50 % | – 10 % |

* procjena iz rezultata B 100 / estimated from B100 results
** prosječno smanjenje svih izmjerenih komponenti / average reduction of all components measured

Rezultati istraživanja ECOTEC-a o emisijama $NO_x$ tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva potvrdili su saznanja ETSU (Energy Technology Support Unit) i njihovu višu vrijednost od emisija $NO_x$ iz dizelskoga goriva. Glavni razlog tomu su emisije iz poljoprivrednih vozila koja se koriste tijekom uzgoja uljane repice. ECOTEC-ove analize emisija tijekom ekstrakcije i rafinacije biodizelskoga goriva pokazale su više vrijednosti nego što su to vrijednosti koje je procijenio ETSU [4] i [16].

Emisije nastale tijekom faze uporabe bile su približno iste za vozila koja su koristila dizelsko gorivo kao i ona koja su koristila biodizelsko gorivo – oboje su imali emisije neznatno iznad 1 000 mg/km, a razlike nisu bile statistički značajne. Istraživanje provedeno u Austriji ukazuje na moguće smanjenje emisija $NO_x$ iz biodizelskih motora od 25 %, poboljšanjem vremena ubrizgavanja goriva. Istraživanje pak provedeno na Sveučilištu u Limericku potvrdilo je ETSU-ova saznanja o sličnosti emisija $NO_x$ iz biodizelskih i dizelskih motora (bez mijenjanja vremena ubrizgavanja).

Neki od zaključaka različitih znanstvenih studija su sljedeći:

– prilagodba vremena ubrizgavanja i temperature djelovanja motora rezultirat će smanjenjem emisije $NO_x$ iz biodizelskoga goriva ispod razine emisije $NO_x$ iz mineralnog dizela [17],
– različiti istraživači zapazili su povećanje emisije $NO_x$ iz biodizelskoga goriva. Međutim,

Results of ECOTEC into $NO_x$ emissions during the production and use of biodiesel fuel cycle have confirmed the findings of ETSU (Energy Technology Support Unit) and its higher value than the emission of $NO_x$ from fossil diesel. The main reason for this is the emissions from farm vehicles that are used during the cultivation of oilseed rape. ECOTEC analyses of emissions during the extraction and refining of biodiesel have shown higher values than those estimated by ETSU [4] and [16].

Emissions created during the use phase were approximately similar for vehicles using fossil diesel and those using biodiesel – both had emissions slightly above 1000 mg/km, the differences being statistically insignificant. Research carried out in Austria shows that it is possible to reduce $NO_x$ emissions from biodiesel engines for a 25 % with improvement in the fuel injection time. Research carried out at the University of Limerick has confirmed the ETSU results about the similarity of emissions of $NO_x$ from biodiesel and fossil diesel engines (without changing injection times).

Some of the conclusions of different scientific studies are as follows:

– the adjustment of the injection time and the temperature at which the engine works will result in a reduction of the emission of $NO_x$ to below the level of $NO_x$ from fossil diesel [17],
– various researchers have noticed an increase in the emission of $NO_x$ from biodiesel fuel.

podaci pokazuju dosljedno smanjenje $NO_x$ u svim testovima s dinamometrom [14],

- povećanjem razine $NO_x$ došlo je do smanjenja čestica, CO i ukupnih ugljikovodika, a usporavanjem vremena ubrizgavanja smanjila se i emisija $NO_x$ [18].

Istraživanje emisija $SO_x$, prema ETSU , koje je provedeno tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva, postavilo je sumnju da je emisija $SO_x$ iz biodizelskoga goriva viša od dizelskoga goriva. Tome, prema njihovom mišljenju uvelike je doprinio postupak istiskivanja ulja iz sjemenke. Međutim, istraživanja agencije ECOTEC [4] su pokazala da je ova pretpostavka netočna.

Prema njihovim istraživanjima, emisije $SO_x$ su tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva bile od 20 % do 30 % manje od onih dizelskoga goriva. Ova saznanja su u suprotnosti sa saznanjima ETSU, koji su uočili visoke razine emisija tijekom tiještenja sjemenki uljarica uporabom električne energije. Uvođenje dizelskih goriva s niskom i vrlo niskom koncentracijom sumpora moglo bi dovesti do smanjenja emisija $SO_x$ iz konvencionalnih motora, ali će omjer ciklusa i dalje biti veći kod dizelskoga goriva nego kod biodizelskoga zbog emisija nastalih tijekom proizvodnje goriva [4] i [16].

Emisija čestica uvelike ovisi o trenutačnoj aktivnosti vozila. Sagorijevanje slame i rad poljoprivredne mehanizacije također su značajni izvori emisija. ETSU nije zabilježila čimbenike emisije u ekstrakciji i rafinaciji dizelskoga goriva. Analiza u kojoj se koristi procjena okoliša upućuje da emisije iz navedenih izvora iako su signifikantne, nisu dovoljno velike da bi utjecale na analize ciklusa proizvodnje i uporabe [15].

Emisija hlapivih organskih tvari znatno se povećava tijekom proizvodnje goriva. Analiza ciklusa proizvodnje i uporabe upućuje da emisija iz biodizelskoga goriva iznosi 44 % do 56 % emisije iz dizelskoga goriva.

Emisija CO tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva je 20 %, odnosno 40 % veća od emisije dizelskoga goriva i to zbog korištenja mineralnoga dizelskoga goriva tijekom uporabe poljoprivredne mehanizacije i sakupljanja i uporabe slame. Vjerojatno je za očekivati da će dizelski motori biti manje važan izvor emisije CO zbog striktnih standarda novih vozila vezanih za emisiju tvari, a koji su poboljšali performanse motora.

Istraživanje EPA (Environmental Protection Agency) o sastavu čađi iz dizelskoga i biodizelskoga goriva

However, data show a consistent reduction of $NO_x$ in all tests with a dynamometer [14],

- with an increase in the $NO_x$ level came a reduction in particles, CO and total hydrocarbons, and with a deceleration of the injection time the emission of $NO_x$ was reduced [18].

Research into $SO_x$ emissions according to ETSU, carried out during the whole biodiesel fuel production and use cycle raised the suspicion that the $SO_x$ emissions from biodiesel fuel were higher than those of fossil diesel. In their opinion, this was greatly contributed to by the procedure for pressing the oil from the seeds. However, researchers by ECOTEC [4] showed that this assumption was incorrect.

According to their research, $SO_x$ emissions during the whole biodiesel fuel production and use cycle were 20 % to 30 % lower than those of fossil diesel fuel. This result is opposite to that of ETSU, who observed high levels of emissions during the pressing of oilseeds with the use of electricity. The introduction of diesel fuels with low and very low concentrations of sulphur might lead to the reduction of the emissions of $SO_x$ from conventional engines, but the ratio of cycles will still be greater with fossil diesel fuel than with biodiesel because of emissions produced during the production of the fuel [4] and [16].

The emission of particles greatly depends on the activity of a vehicle at a given time. Burning straw and the work of farm machinery are also important sources of emissions. ETSU has not recorded the factors of emissions in the extraction and refining of fossil diesel. Analysis using environmental evaluation suggests that emissions from these sources although very significant are not great enough to be able to affect analyses of the production and use cycle [15].

The emission of volatile organic substances is increased considerably during the production of the fuel. Analysis of the production and use cycle suggests that emissions from biodiesel fuel are between 44 % and 56 % of the emissions deriving from fossil diesel.

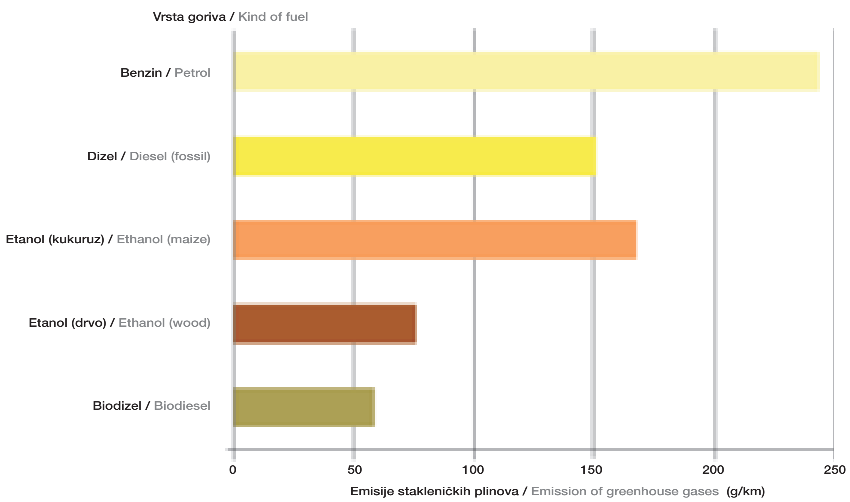
Emission of CO during the production and use cycle of biodiesel is 20 % or 40% up on emission from fossil diesel, which is the result of the use of mineral diesel while operating farm machinery and the collection and use of the straw. It is to be expected that diesel engines will be a less important source of CO emission because of the stringent standards for new vehicles related to the emission of substances and that have improved the performances of engines.

Research by the EPA (Environmental Protection Agency) concerning the composition of soot deriving from fossil and biodiesel fuels shows a reduction of ukazuje na smanjenje ukupne čađi pri uporabi biodizela za 17 %, odnosno za 21 % (hladni, odnosno vrući FTP – Federal Test Procedure). Kod uporabe biodizela emisija čađi (netopive čestice) značajno se smanjuje (za 54 % ili za 51 %), ali je udio emisije čestica sastavljenih od ugljikovodika (čestice topive u gorivu), mnogo veći. Navedeno ukazuje na mogućnost da biodizelsko gorivo ne izgara potpuno istom brzinom kao mineralno dizelsko gorivo, no također se mora napomenuti da su emisije plinovitih ugljikovodika smanjene prilikom uporabe biodizelskog goriva. Budući da se zabrinutost koja se odnosi na čestice povećava djelomično i zbog potencijalnih negativnih učinaka topive frakcije, može se činiti da bi emisije iz biodizelskoga goriva mogle biti još štetnije [15].

Usporedba emisija stakleničkih plinova pri proizvodnji i uporabi različitih goriva prikazana je na slici 2, s koje je vidljivo da su emisije stakleničkih plinova iz biodizelskoga goriva najniže, a slijedi ih bioetanolsko gorivo dobiveno iz drveta [15]. Emisije stakleničkih plinova tijekom proizvodnje dizelskoga goriva iznose 32 g/km, što je gotovo polovica emisija do kojih dolazi prilikom proizvodnje biodizelskoga goriva, čak i kada se umjesto električne energije u procesu proizvodnje koristi slama. Međutim, kada se govori o emisiji $CO_2$ tijekom izgaranja samog dizela (245 g/km) argumenti su izrazito na strani biodizela (75 g/ km).

total soot in the use of biodiesel of 17 % to 21% (cold, or hot FTP – Federal Test Procedure). In the case of biodiesel use, the emission of soot (insoluble particles) was significantly reduced (by 54 % or 51 %) but the proportion of the emission of particles composed of hydrocarbons (particles soluble in fuel) is much higher. This suggests the possibility that biodiesel does not combust at precisely the same speed as fossil diesel, but it should also be mentioned that the emissions of gaseous hydrocarbons are reduced because of the use of it. Since concern that relates to particles has increased partially because of the potentially negative effects of soluble fractions, it might seem that the emissions from biodiesel fuel might be even more harmful [15].

A comparison of the emissions of greenhouse gases in the production and use of differing fuels is shown in Figure 2, from which it can be seen that the emissions of greenhouse gases from biodiesel fuels are the lowest, after which comes bioethanol fuel obtained from wood [15]. Emissions of greenhouse gas during the production of diesel fuel come to 32 g/km, which is almost half the emissions arising during the production of biodiesel fuel, even when instead of electricity straw is used in the production process. However, when one talks of the emission of $CO_2$ during the combustion of the fossil diesel fuel itself (245 g/km), the arguments are markedly on the side of biodiesel (75 g/km).




**Slika 2**
Ciklus stakleničkih plinova pri proizvodnji i uporabi kod različitih goriva ($CO_2$-$CO_2$ ekvivalent ostalih zagađivača $CH_4$ i $N_2O$)
**Figure 2**
Cycle of greenhouse gases in the production and use of various fuels ($CO_2$-$CO_2$ equivalent of other polluters $CH_4$ and $N_2O$)

Mora se naglasiti da prikazani rezultati vrijede do trenutka dok poljoprivredna proizvodnja koristi dizelsko gorivo u svojoj primarnoj proizvodnji. Međutim, uporabom biodizelskoga goriva navedene vrijednosti past će za više od 60 %.

It has to be pointed out that the results shown hold true as long as agricultural production uses diesel fuel in its primary production. But when biodiesel is used, these values will drop by more than 60 %.

## 3 VEGETABILNA ULJA KAO SIROVINE ZA PROIZVODNJU BIODIZELA U SVIJETU

Četiri uljane kulture jasno dominiraju kao upotrebljeni izvori biljnog ulja za dosadašnju svjetsku proizvodnju biodizela. Na prvom mjestu je ulje uljane repice s oko 85 %, a slijede suncokretovo ulje, sojino ulje, palmino ulje i ostali izvori (laneno ulje, goveđi loj i reciklirano korišteno ulje iz kuhinja). Iz podataka u tablici 5 vidljivo je da su uljana repica, soja, suncokret i uljana palma glavne uljane kulture koje se kultiviraju za dobivanje ulja za humanu konzumaciju kao i druge različite proizvode prehrambene industrije.

## 3 VEGETABLE OILS AS RAW MATERIALS FOR THE PRODUCTION OF BIODIESEL WORLDWIDE

Four oil crops clearly dominate as sources used for vegetable oil in world experience of biodiesel production to date. In first place comes oilseed rape oil, which accounts for about 85% of the total, then sunflower oil, soy oil, palm oil and other sources (linseed, suet and recycled cooking oil). The figures in Table 5 shows that oilseed rape, soy, sunflower and palm oil are the main crops cultivated for oil for human consumption as well as other various diverse products of the food industry.

Tablica 5 – Sadašnja svjetska proizvodnja devet glavnih vegetabilnih ulja [19]
Table 5 – Current world production of nine main vegetable oils [19]

| Vegetabilna ulja / Vegetable oils | Procijenjena proizvodnja / Estimated production 2003.–2004. ($10^6$ t) |
|---|---|
| Soja / Soy | 31,83 |
| Palma / Palm | 28,13 |
| Uljana repica / Oilseed rape | 12,57 |
| Suncokret / Sunflower | 9,42 |
| Zemni orašac / Groundnut | 4,81 |
| Sjeme pamuka / Cottonseed | 3,90 |
| Palmina jezgra / Palm kernel | 3,50 |
| Kokosov orah / Coconut | 3,33 |
| Maslina / Olive | 2,81 |
| Ukupno / Total | 100,29 |

S uljanom repicom, suncokretom i sojom moguće je proizvoditi, odnosno dopuniti potrebe masnih kao i jednim dijelom bjelančevinastih komponenata hrane u vlastitoj zemlji. Pored hranidbenih masnih sastojaka, ulje se može upotrijebiti i u tehničke svrhe kao sirovina ili pogonsko gorivo. Mijenjanjem prehrambenih navika i prelaskom na vegetabilna ulja i masnoće značajno se povećala i njihova potrošnja. Tako su površine pod glavnim uljaricama u svijetu u poslijednjih 30 godina porasle 2,5 do 3 puta, a njihova ukupna proizvodnja – zbog povećanja prosječnih prinosa primjenom suvremene tehnologije – 4 do 6 puta (tablica 6).

With oilseed rape, sunflower and soy it is possible to produce or supplement the needs for fats and part of the needs for the protein components of food in the home country. In addition to the nutritious components of fats, oils can be used for process purposes as raw materials or drive fuel. With changes in food habits and a major shift to vegetable oils and fats, the consumption of these products has much increased. Thus the land areas devoted to the main oil producing plants in the world have risen some 2.5 to 3 times in the last 30 years in the world at large, and their total production – because of the increase in average yields with the use of contemporary technology – has gone up fourfold or sixfold (Table 6).

Tablica 6 – Trendovi zasijanih površina i proizvodnje glavnih uljarica u svijetu [20]
Table 6 – Trends in areas sown and production of the main oil bearing plants in the world [20]

| Godina / Year | Zasijana površina / Areas sown ($10^3$ ha) | | | Proizvodnja / Production ($10^3$ t) | | |
|---|---|---|---|---|---|---|
| | Uljana repica / Oilseed rape | Suncokret / Sunflower | Soja / Soy | Uljana Repica / Oilseed rape | Suncokret / Sunflower | Soja / Soy |
| 1975. | 9 911 | 9 246 | 38 767 | 8 768 | 9 873 | 64 248 |
| 1980. | 10 992 | 12 424 | 50 648 | 10 757 | 13 656 | 81 039 |
| 1985. | 14 756 | 14 842 | 53 066 | 19 241 | 18 856 | 10 156 |
| 1990. | 17 610 | 16 999 | 57 184 | 24 428 | 22 666 | 108 453 |
| 1995. | 23 816 | 20 894 | 62 510 | 34 185 | 26 255 | 126 981 |
| 2000. | 25 833 | 21 087 | 74 399 | 39 515 | 26 434 | 161 346 |
| 2005. | 26 950 | 23 339 | 91 929 | 46 409 | 31 066 | 209 976 |

Stvaranje i uvođenje u proizvodnju novih 00 - kultivara uljane repice, poboljšane kakvoće ulja i sačme, omogućilo je brzo širenje ove kulture osobito u Europi, gdje je postala najvažnija uljarica. Samo u Njemačkoj i Francuskoj proizvodi se na preko 2,5 milijuna hektara, što su za preko milijun hektara veće površine u odnosu na one s početka devedesetih godina (tablica 7).

Interes za ovom kulturom još više je porastao utemeljenjem postupka dobivanja biodizelskoga goriva iz ulja uljane repice i izgradnje preradbenih kapaciteta u mnogim europskim državama (Austriji, Njemačkoj, Francuskoj, Češkoj i dr.). Procjenjuje se da je u Njemačkoj moguće biodizelom zamijeniti 5 % potrošnje mineralnog dizela, a da je ukupni potencijal zamjene dizela u Europskoj uniji čak 10 %. Pri postupku proizvodnje biodizela, kao nusproizvod ostaje sačma (1 000 kg sjemena uljane repice daje 380 l biodizel goriva i 620 kg sačme), koja se može koristiti u krmnim smjesama. Danas se u mnogim europskim državama planira sjetva uljane repice za potrebe prehrane ljudi i za kemijsku industriju (food and non-food rapeseed).

The creation and bringing into production of the new 00-cultivars of oilseed rape and the improved quality of oil and meal have enabled rapid expansion of this crop, particularly in Europe, where it has become the most important oil bearing plant. In France and Germany alone it is produced on over 2,5 million hectares, which is a million hectares more than that at the beginning of the nineties (Table 7).

The interest in this crop rose even more with the establishment of a process for obtaining biodiesel fuel from oilseed rape and the development of processing capacities in many European states (Austria, Germany, France, Czech Republic and elsewhere). It is estimated that in Germany it is possible to use biodiesel to replace 5 % of the fossil diesel oil used, and that the total potential for diesel replacement in European Union is as high as 10 %. In the production process for biodiesel, the meal is left as a by-product (1 000 kg of oilseed rape seeds yield 380 l of biodiesel and 620 kg of meal), which can be used in fodder mixtures. Today in many European countries it is planned to sow oilseed rape for human food and for the chemical industry (food and non-food rapeseed).

Tablica 7 – Trend površina pod uljanom repicom u najvećih proizvođača u svijetu [20]
Table 7 – Trend in areas devoted to oilseed rape in the world's major producers [20]

| Zemlja / Country | Godina / Year | | | | |
|---|---|---|---|---|---|
| | 1985. (ha) | 1990. (ha) | 1995. (ha) | 2000. (ha) | 2005. (ha) |
| Svijet / World | 14 756 000 | 17 610 000 | 23 816 000 | 25 833 000 | 26 950 000 |
| Europa / Europe (25) | 2 180 904 | 2 951 583 | 3 838 448 | 4 056 332 | 4 759 560 |
| Australija / Australlia | 74 154 | 72 886 | 376 558 | 1 459 000 | 1 080 000 |
| Kanada / Canada | 2 783 300 | 2 529 000 | 5 273 000 | 4 859 200 | 5 154 300 |
| Kina / China | 4 494 485 | 5 503 531 | 6 907 012 | 7 494 360 | 7 220 010 |
| Indija / India | 3 986 900 | 4 967 000 | 6 060 000 | 6 026 800 | 6 800 000 |
| Francuska / France | 473 700 | 679 600 | 864 000 | 1 186 255 | 1 211 000 |
| Njemačka / Germany | 409 605 | 722 393 | 973 886 | 1 078 010 | 1 345 300 |
| Velika Britanija / UK | 296 000 | 389 900 | 439 000 | 402 000 | 603 000 |
| Poljska / Poland | 467 021 | 500 374 | 606 382 | 434 768 | 544 490 |
| SAD / USA | 0 | 31 000 | 174 580 | 607 810 | 456 050 |

## 4 MOGUĆNOSTI PROIZVODNJE ULJANE REPICE I BIODIZELA U HRVATSKOJ

Uljanu repicu (Brassica napus L. ssp oleifera) izabrali su pioniri proizvodnje biodizela za eksperimente transesterifikacije zbog njene relativno niske cijene u odnosu na druge uljarice i dobre adaptibilnosti na različite uvjete. K tomu, repica je najraširenija uljana kultura u Europi, napose u Njemačkoj i Francuskoj koje su ujedno vodeće u proizvodnji biodizela.

Budući da ulje repice ima visok sadržaj mononezasićene oleinske kiseline i niski sadržaj obje zasićene i polinezasićene masne kiseline, ono je praktično idealna sirovina za proizvodnju biodizela s obzirom na karakteristike sagorijevanja, oksidativnu stabilnost i ponašanje na niskim temperaturama. Usto, vrlo je poželjna kultura u plodoredu jer svojim intenzivnim zakorjenjivanjem i prožimanjem tla poboljšava pedofizička svojstva tla, a budući da pokriva tlo gotovo 11 mjeseci smanjuje ispiranje hraniva.

Najznačajnije domaće kulture za proizvodnju biljnih ulja su suncokret, soja i uljana repica. U primorskom dijelu Hrvatske proizvodi se maslinovo ulje, dok je proizvodnja i potrošnja drugih ulja kao primjerice bućinog i ulja od klica kukuruza neznatna. Soja u odnosu na uljanu repicu i suncokret sadrži znatno više bjelančevina (oko 40 %), a manje ulja (oko 18 %), pa je pogodna za proizvodnju stočne hrane. U tu svrhu se koristi ili kao ekstrudirano sjeme ili u obliku sačme

## 4 OPPORTUNITIES FOR THE PRODUCTION OF OILSEED RAPE AND BIODIESEL IN CROATIA

Oilseed rape (Brassica napus L. ssp oleifera) was chosen by the pioneers of biodiesel production for transesterification experiments because of its relatively low cost as compared to other oil bearing plants and good adaptability to varying conditions. In addition, rape is the most widely distributed oil crop in Europe, particularly in France and Germany, which are the leaders in the field of biodiesel production.

Since oilseed rape has a large monounsaturated olein acid content and a low content of both saturated and polyunsaturated fatty acid, it is practically an ideal raw material for the production of biodiesel, because of its characteristics in combustion, its oxidative stability and behaviour at low temperatures. In addition, it is a very valuable crop in the rotation, for with its vigorous rooting and spread through the soil it improves the pedophysical properties of the soil and since it covers the ground for almost 11 months, it reduces nutrient run-off.

The most important Croatian crops for the production of vegetable oils are sunflower, soy and oilseed rape. In the coastal part of Croatia olive oil is also produced, while the production and consumption of other oils, such as from pumpkin and corn germ, are insignificant. Soy as compared with rape and sunflower contains much more protein (about 40 %) and less oil (about 18 %), and it is suitable for production for fodder. For this purpose it is used koja zaostaje nakon ekstrakcije ulja. Sojina sačma je glavna bjelančevinasta komponenta u krmnim smjesama, a kako njena proizvodnja nije dostatna za naše potrebe, soja se redovno i u velikim količinama uvozi. Sačma i pogače druge dvije uljarice može u smjesama zamjeniti soju, ali ni te količine nisu dostatne za potrebe stočarstva. Za sada se u nas malo napora ulaže za korištenje sojina sjemena u druge svrhe, prije svega za ljudsku prehranu, dok se u svijetu od soje proizvodi na stotine proizvoda.

Proizvodnja ulja i čvrstih biljnih masnoća iz ove tri uljarice osigurava osnovne prehrambene proizvode bez kojih je nezamisliva suvremena prehrana stanovništva, a bez sačmi i pogača iz njihova sjemena hranidba stoke. Osim toga, uljarice predstavljaju nužne kulture u plodoredu koje omogućuju optimalnu proizvodnju drugih ratarskih kultura.

Proizvodnju uljane repice najbolje je sagledati kroz strukturu zasijanih površina u Republici Hrvatskoj i udio uljarica u strukturi sjetve (slika 3). Prema podacima Državnog zavoda za statistiku u Hrvatskoj je 2003. godine zasijano 1 080 190 ha, a 379 810 ha (26 %) obradivih površina – oranica i vrtova je ostalo nezasijano. Od toga, u posjedu pravnih osoba (poduzeća i poljoprivrednih zadruga) ostalo je nezasijano 114 381 ha (30,1 %), a u posjedu obiteljskih poljoprivrednih gospodarstava 265 429 ha (69,9 %).

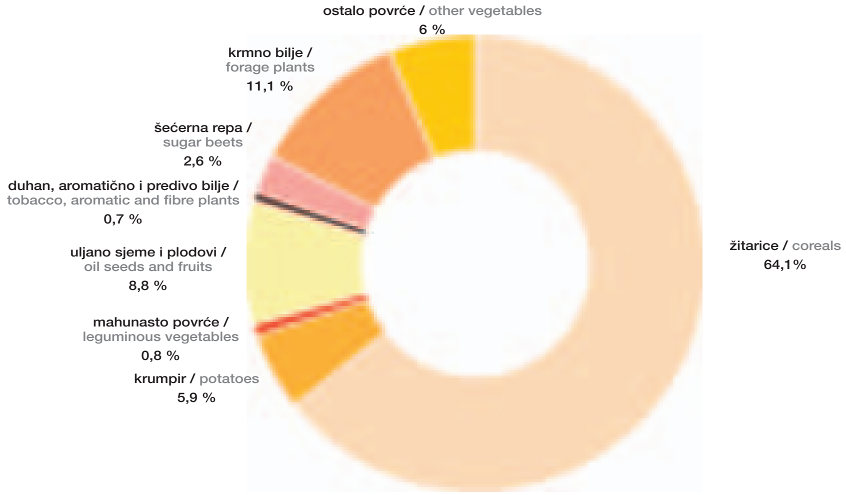
U strukturi sjetve najviše su zastupljene žitarice (64,1 %). Industrijskim biljem zasijano je 130 914 ha (12,1 %), a uljarice su bile zastupljene sa svega 8,7 %.

either as extruded seed or in the form of the meal that remains after the extraction of the oil. Soy meal is the main protein component in fodder mixes, and since the production of it is not enough for local needs, soy is regularly imported in large quantities. Meal and cake of the other two oil bearing plants can replace soy in mixes, but not even the quantities of them are enough for the needs of animal husbandry. For the moment, little effort is being made in this country to use soy beans for other purposes, above all for human food, while in the world at large hundreds of products are made from soy.

The production of oil and solid fats from these three oil bearing plants provides the basic food products without which contemporary diet of the population is unimaginable, and without the meal and cake from their seeds, the feeding of livestock. Apart from this, the oil bearing plants are necessary crops in the rotation, which enable optimum production of other arable crops.

The production of oilseed rape can be looked at via the structure of hectares sown in the Republic of Croatia, and the proportion of oil bearing plants in the structure of all crops sown (Figure 3). According to the data of the Croatian Bureau of Statistics, in Croatia all told 1 080 190 ha were sown, 379 810 ha (26 %) of cultivable land remained uncultivated (arable and horticultural land). Of this sum, 114 381 ha (30,1 %) of uncultivated land belonged to the corporate sector (firms and cooperatives) while 265 429 ha (69,9 %) of land belonging to small family farms were uncultivated.

In the structure of the sowing, cereals were most highly represented (64,1 %), while 130 914 ha were sown with industrial crops (12,1%) while oil-bearing crops accounted for no more than 8,7%.




**Slika 3**
Ukupno zasijane površine u Hrvatskoj u 2003. [21]
**Figure 3**
Total area of land sown in Croatia in 2003 [21]

Sva ekstenzivnost naše ratarske proizvodnje vidljiva je iz pregleda strukture sjetve na obiteljskim poljoprivrednim gospodarstvima. Na 78,4 % oraničnih površina obiteljskih poljoprivrednih gospodarstava zasijano je svega 8,8 % industrijskim kulturama, a uljaricama tek 5,1 %. Posebno je zapostavljena uljana repica, koja je na obiteljskim poljoprivrednim gospodarstvima bila zasijana na samo 4 430 ha (0,5 %). Dakle, individualni poljoprivredni proizvođači ne prihvaćaju uljanu repicu, iako je ona:

– kultura koja se biološki i organizacijski odlično uklapa u sustav ratarske proizvodnje (pšenica – uljana repica – kukuruz),
– relativno stabilnih i sigurnih prinosa koji u posljednja dva desetljeća gotovo da nisu padali ispod prosječno 2,0 t/ha, ni u klimatski ekstremno nepovoljnim godinama i uz vrlo nisku razinu primjenjene tehnologije,
– kultura koja daje kvalitetno ulje za humanu konzumaciju i po kriterijima najzahtjevnijih nutricionista, a uvođenjem 00-kultivara daje i sačmu bitno smanjenog sadržaja glukozinolata, koja se neškodljivo koristi u hranidbi većine vrsta i kategorija životinja [22].

Zastupljenost uljane repice, suncokreta i soje u strukturi biljne proizvodnje iznosila je 8,7 % od ukupno zasijanih površina 2003. godine (1 080 190 ha). Glavne tri uljarice uzgajale su se u Hrvatskoj te godine na ukupno 93 595 ha (tablica 8 i slika 4). U strukturi proizvodnje uljarica, uljana repica je sudjelovala s 15 524 ha (16,61 %), suncokret s 28 211 ha (30,0 %) i soja s 49 860 ha (53,4 %). Jedan dio soje gospodarski subjekti zadržavaju za vlastite potrebe (tržnost se kreće od 40 % do 80 % ovisno o godini) te su ukupno otkupljene količine uljarica za preradu manje od ukupno proizvedenih količina. Općenito se može reći da je proizvodnja uljarica u Hrvatskoj relativno niska i sa izrazitim variranjem i površina i prosječnih prinosa po godinama.

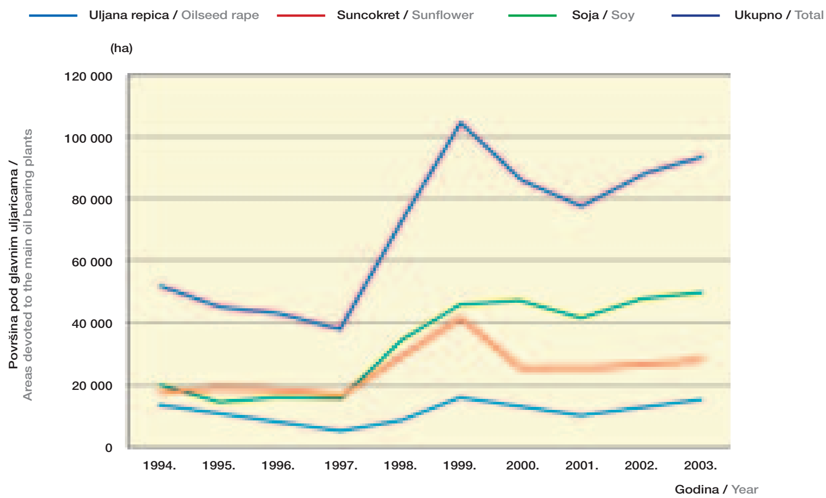
Just how extensive Croatian arable farming is can be seen from the survey of the structure of the crops on small family farms. On the 78,4 % of the total ploughland belonging to family farms, no more than 8,8 % industrial crops were planted, and only 5,1 % oil bearing plants. Oilseed rape was particularly neglected, and was sown on family farms on only 4 430 ha, or 0,5 %. Thus the individuals small farmers have not accepted oilseed rape, although it:

– is a crop that fits in excellently, biologically and in organisational terms, to the system of arable production (in a rotation consisting of wheat, oilseed rape and maize),
– has quite stable and certain yields, which in the last two decades almost have not fallen below an average of 2,0 t/ha, not even in climatically extremely unfavourable years, and with a very low level of technology applied,
– is a crop that gives a high quality oil for human consumption even according to the criteria of the most demanding nutritionists, and with the introduction of the 00-cultivar gives a meal with a highly reduced content of glucosynolate, which can be used without any downsides in the food of most species and categories of animals [22].

All told, oilseed rape, sunflower and soy amounted to 8,7% of the structure of plant production, from the 1 080 190 ha of land sown in 2003. These three oil bearing plants were cultivated in Croatia in that year on a total of 93 595 ha (Table 8 and Figure 4). In the structure of the production of oil bearing plants, oilseed rape accounted for 15 524 ha (16,61 %), sunflower for 28 211 ha (30,0 %) and soy for 49 860 ha (53,4 %). Some of the soy was kept by the farmers for their own needs (about 40 % to 80 % of the crop is placed on the market depending on the given year) and quantities of oil bearing plants bought for processing are less than the quantities totally produced. In general it can be said that the production of oil bearing plants in Croatia is quite low, with marked variations in areas and in average yields per year.

Tablica 8 – Površine pod glavnim uljaricama u Hrvatskoj [21]
Table 8 – Areas devoted to the main oil bearing plants in Croatia [21]

| | Površine pod glavnim uljaricama / Areas devoted to the main oil bearing plants (ha) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1994. | 1995. | 1996. | 1997. | 1998. | 1999. | 2000. | 2001. | 2002. | 2003. |
| Uljana repica / Oilseed rape | 13 889 | 10 982 | 7 651 | 5 356 | 8 949 | 16 234 | 12 886 | 10 319 | 13 041 | 15 524 |
| Suncokret / Sunflower | 17 871 | 19 385 | 18 849 | 16 946 | 28 642 | 41 996 | 25 715 | 25 336 | 26 835 | 28 211 |
| Soja / Soy | 20 435 | 15 018 | 16 423 | 16 030 | 34 015 | 46 336 | 47 484 | 41 621 | 47 897 | 49 860 |
| Ukupno / Total | 52 195 | 45 385 | 42 923 | 38 332 | 71 606 | 104 566 | 86 085 | 77 276 | 87 773 | 93 595 |




**Slika 4**
Dinamika površina pod glavnim uljaricama u Hrvatskoj
**Figure 4**
Dynamics of areas devoted to the main oil bearing plants in Croatia

Tablica 9 – Prosječni prinosi uljarica u Hrvatskoj [21]
Table 9 – Average yields of oil bearing plants in Croatia [21]

| | Prosječni prinosi uljarica / Average yields of oil bearing plants (t/ha) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1994. | 1995. | 1996. | 1997. | 1998. | 1999. | 2000. | 2001. | 2002. | 2003. |
| Uljana repica / Oilseed rape | 2,04 | 2,23 | 1,52 | 2,09 | 2,45 | – | 2,28 | 2,18 | 1,96 | 1,84 |
| Suncokret / Sunflower | 1,48 | 1,91 | 1,51 | 2,13 | 2,17 | 1,72 | 2,10 | 1,70 | 2,35 | 2,45 |
| Soja / Soy | 2,16 | 2,29 | 2,19 | 2,46 | 2,28 | 2,50 | 1,38 | 2,21 | 2,70 | 1,66 |

Prosječni prinosi uljane repice od 2,2 do 2,5 t/ha su vrlo niski. Ovo je razumljivo kada se zna da se repica najčešće uzgaja na najlošijim, neuređenim tlima, loših vodo-zračnih svojstava i s izraženim depresijama u kojima površinska voda stagnira, što dovodi do redukcije sklopa i stvaranja plješina u usjevu. Zastarjela i neadekvatna mehanizacija, niska razina primijenjene tehnologije, manjkava zaštita usjeva i nedovoljna educiranost obiteljskih gospodarstava, daljnji su važni razlozi malih površina pod repicom i niskih prosječnih prinosa, odnosno ukupne proizvodnje.

Glavnina proizvodnje uljane repice odvija se na proizvodnom području Osječko-baranjske županije.

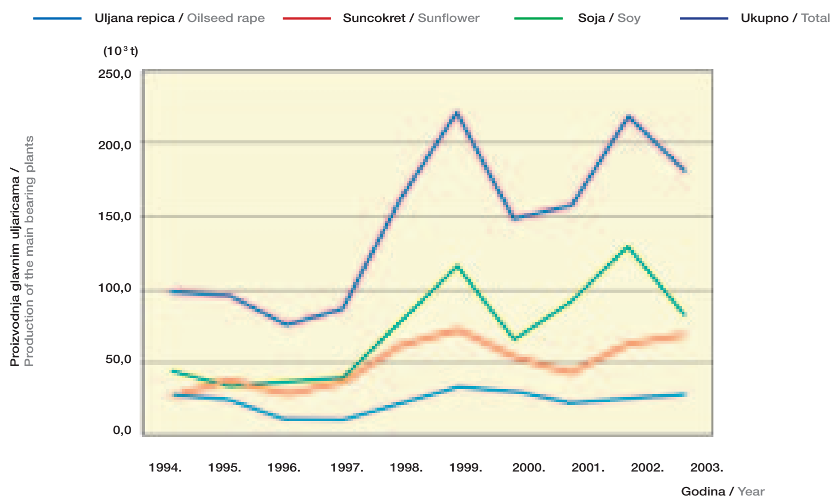
Average yields of oilseed rape of 2,2 to 2,5 t/ha are extremely low. This is understandable when one takes into consideration that rape is often grown on the worst and least improved soils, with poor water and air properties and with marked depressions in which the surface water tends to stagnate, which leads to a reduction of plant density and gap formation. Obsolescent and inappropriate machinery, low level of technology applied, poor pest control and insufficient education of family farms are further very important reasons for the small areas devoted to rape and to the small average yields, that is, of total production.

Most of the production of oilseed rape takes place in the area of the Osiječko-baranjska County,

Tablica 10 – Proizvodnja glavnih uljarica u Hrvatskoj [21]
Table 10 – Production of the main oil-bearing plants in Croatia [21]

| | Proizvodnja glavnih uljarica / Production of the main oil-bearing plants ($10^3$ t) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1994. | 1995. | 1996. | 1997. | 1998. | 1999. | 2000. | 2001. | 2002. | 2003. |
| Uljana repica / Oilseed rape | 28,3 | 24,5 | 11,7 | 11,2 | 22,0 | 32,6 | 29,4 | 22,5 | 25,6 | 28,6 |
| Suncokret / Sunflower | 26,5 | 37,1 | 28,5 | 36,1 | 62,2 | 72,4 | 54,0 | 43,0 | 63,0 | 69,3 |
| Soja / Soy | 44,1 | 34,3 | 35,9 | 39,5 | 77,5 | 115,9 | 65,3 | 91,9 | 129,5 | 82,6 |
| Ukupno / Total | 98,9 | 95,9 | 76,1 | 86,8 | 161,7 | 220,9 | 148,7 | 157,4 | 218,1 | 180,5 |

**Slika 5**
Proizvodnja glavnih uljarica u Hrvatskoj
**Figure 5**
Production of the main oil bearing plants in Croatia




Ukupna proizvodnja uljane repice u posljednjih 10 godina u Republici Hrvatskoj najčešće se kretala od 11 000 t do 24 000 t, a tek je 1999. godine dostigla predratnu proizvodnju od preko 30 000 t sirovine (tablica 10 i slika 5). Nedovoljan interes i premalo sudjelovanje uljane repice u strukturi sjetve na našim oranicama posljedica su mjera ekonomske politike u području agrara, posebno politike cijena, te nedovoljne zainteresiranosti prerađivačke industrije.

Za podmirenje sadašnjih potreba potrošnje bilo bi potrebno osigurati godišnje 73 000 t sirovog ulja i to:

– sojina ulja 25 000 t ili 150 000 t sojina sjemena,
– ulja uljane repice 8 000 t ili 20 000 t sjemena uljane repice,
– suncokretova ulja 40 000 t ili 100 000 t suncokretova sjemena.

Procjenjuje se da su potrebe stočarstva Hrvatske oko 200 000 t sačmi godišnje i to:

– 160 000 t (do190 000 t) sojine sačme,

Total production of rape in the last 10 years in the Republic of Croatia has mostly ranged between 11 000 and 24 000 tons, and it was only in 1999 that the pre-war production of over 30 000 t of raw material was attained once again (Table 10 and Figure 5). Lack of interest and the insufficient proportion of oilseed rape in the structure of the crops in the ploughland of this country are the results of measures of economic policy in the agrarian domain, particularly the price policy, and the insufficient interest expressed by the processing industry.

To cover current needs for consumption it is necessary to provide annually 73 000 t of raw oil, as follows:

– soy oil, 25 000 t or 150 000 t of soy beans,
– oilseed rape oil, 8 000 t or 20 000 t of rapeseeds,
– sunflower soil, 40 000 t or 100 000 t of sunflower seeds.

It is estimated that the Croatian animal husbandry industry needs about 200 000 t of meal a year, as follows:

– 30 000 t suncokretove sačme,
– 10 000 t sačme uljane repice.

Uzmu li se u obzir postojeći zemljišni resursi, naše potrebe za sirovim uljem (i sačmom) za prehranu zadovoljili bi zasijavanjem 120 000 ha do 130 000 ha s uljaricama, tj. oko 12 % obradivih površina. Zbog svoje međusobne i samoinkopatibilnosti u plodoredu (zajedničke bolesti) uljarice se mogu vratiti na isto tlo tek nakon 4 do 5 godina, što limitira njihovu proizvodnju na maksimalno 230 000 ha godišnje.

Daljnje povećanje površina pod uljanom repicom za neprehrambeni lanac (biodizel) moguće je, osim značajnijim povećanjem površina u postojećem uskom plodoredu, i rekultivacijom zapuštenih i neobrađivanih površina, čime bi se osigurale nove zasijane površine u pravilnom plodoredu od 60 000 do 70 000 ha, odnosno vlastita proizvodnja biodizelskoga goriva od 60 000 t do 70 000 t. Realna mogućnost povećanja ukupne proizvodnje repice je i povećanjem prosječnih prinosa na 3,0 do 3,5 t/ha, za što postoje i agroekološki i tehnološki uvjeti. Time bi se na spomenutim novozasijanim površinama repicom povećala proizvodnja za preko 30 %, odnosno osigurala sirovina za proizvodnju 90 000 t do 100 000 t biodizela. Za ostvarenje ovih ciljeva potrebno je [23]:

– mjerama ekonomske politike u agraru, napose cijenama i novčanim poticajima stimulirati proizvođače na značajnije uključivanje ove kulture u strukturu sjetve,
– uvoditi i primijeniti suvremenu tehnologiju proizvodnje repice na svim zasijanim površinama (uvođenje hibrida i sortne tehnologije, optimalna ishrana i zaštita usjeva), kako bi se ostvarili realno mogući prosječni prinosi iznad 3,0 t/ha,
– zamijeniti zastarjelu mehanizaciju novim suvremenim strojevima za obradu i pripremu tla, sjetvu i njegu usjeva, napose novih kombajna kojima je moguća brza i pravovremena žetva i kojima se gubici u žetvi smanjuju na minimum,
– kontinuirano educirati proizvođače, napose obiteljska gospodarstva koja nemaju proizvodnih iskustava s ovom kulturom o suvremenim agrotehničkim mjerama.

– 160 000 t (and up to 190 000 t) of soy meal,
– 30 000 t of sunflower meal,
– 10 000 t of oilseed rape meal.

If the existing land resources are taken into consideration our needs for raw oil (and meal) for food would be met by the sowing of 120 000 ha to 130 000 ha with oil bearing plants, i.e., about 12 % of totally cultivable land. Because of their reciprocal and self-incompatibility in the rotation (common diseases) oil bearing plants can be put back on the soil only after 4 to 5 years, which limits their production to a maximum of 230 000 ha p.a.

Further increase of land devoted to oilseed rape for the non-food chain (biodiesel) is possible, apart from a major increase in the land in the existing narrow rotation system, also by recultivation of abandoned and uncultivated land, which would provide newly sown land in a regular rotation of 60 000 to 70 000 ha, that is, a home production of biodiesel fuel of from 60 000 t/year to 70 000 t/ year. The realistic opportunity for increasing the overall production of rape is by increasing average yields to 3,0 t/ha to 3,5 t/ha, which is completely possible given the agroecological and technological conditions. Thus production on the mentioned areas newly sown with rape would increase production to over 30%, that is, it would provide the raw materials for the production of 90 000 t to 100 000 t of biodiesel. In order to attain these goals, it is necessary to:

– incentivise the producers, by economic policy measures in agriculture, particularly with prices and monetary incentives, to bring this crop much more into the structure of their production,
– introduce and applied contemporary technology of the production of rape on all areas sown (introduction of hybrids and variety technology, optimum nutrients and pest control for the crops), so as to ensure the realistically possible average yields of over 3,0 t/ha,
– replace the obsolescent mechanisation with new and contemporary machinery for the tillage of the soil, sowing and crop care, especially with new combine harvesters with which a rapid and correctly-timed harvest is possible, with losses in the harvesting reduced to the minimum,
– continuously educate the producers, particularly small family farmers, who have no production experience with this crop and with contemporary agricultural and technical measures.

# 5 ZAKLJUČCI

Biodizel je ekološki prihvatljivo alternativno gorivo za dizel motore koje se dobiva transesterifikacijom iz biljnih ulja i životinjskih masti kao obnovljivih resursa. Danas su poznata brojna pozitivna svojstva koja karakteriziraju gorivo iz biljnih ulja [24]:

– biološki ciklus ugljika je zatvoren jer uljane biljke tijekom porasta usvajaju iz zraka ukupni ugljik koji se oslobađa u formi $CO_2$ pri sagorijevanju goriva,
– bilanca energije goriva iz biljnih ulja je pozitivna, što znači da je Sunčeva energija uskladištena u biljnom ulju značajno veća od one upotrijebljene za njegovu proizvodnju,
– gorivo iz biljnih ulja nedvojbeno manje opterećuje okoliš u odnosu na mineralno dizelsko gorivo jer se njegovim sagorijevanjem oslobađa manje klimadjelotvornih škodljivih tvari (smanjena emisija štetnih ispušnih plinova za preko 50 %, $CO_2$ – neutralno, ne sadrši sumpor, fosfor i olovo, značajno smanjena količina čađi, smanjena količina nesagorjelih ugljikovodika, CO i krutih čestica). K tomu je značajno manje toksično i ima bolju biorazgradivost u vodi i tlu, te izrazito bolja maziva svojstva.

Kao sirovine za proizvodnju biodizela mogu se upotrijebiti i korištena kuhinjska ulja, ali su ona dostupna u manjim količinama. Glavne sirovine su ulja uljanih kultura iz agrarne proizvodnje, napose ulje uljane repice iz kojega se danas proizvodi preko 85 % ukupne svjetske proizvodnje biodizela.

U Hrvatskoj proizvodnja uljarica i ulja nije dostatna niti za potrebe prehrane stanovništva i stočarstva, zbog njihovog niskog udjela u strukturi sjetve, niskih prosječnih prinosa, nezainteresiranosti prerađivačke industrije, kao i obiteljskih gospodarstava, zbog slabih ekonomskih učinaka u njihovoj proizvodnji. Značajnije povećanje proizvodnje uljarica i za potrebe neprehrambenog lanca (proizvodnju biodizela) moguće je povećanjem površina pod ovim kulturama na preko 200 000 ha, što omogućavaju zemljišni resursi i dopuštaju zahtjevi optimalnog plodoreda, te značajnijim povećanjem njihovih prosječnih prinosa (> 30 %) uvođenjem suvremene tehnologije. Tako bi se osigurale dostatne količine ulja (i sačme) za potrebe prehrane i stočarstva, te sirovina za 90 000 do 100 000 tona biodizela.

# 5 CONCLUSIONS

Biodiesel is an ecologically acceptable alternative fuel for diesel engines, which is obtained by transesterification from plant oils and animal fats, renewable resources. Today numerous positive properties that characterise fuel from plant oils are known [24]:

– the biological carbon cycle is closed because during their growth oil-bearing plants capture from the air total carbon that is liberated in the form of $CO_2$ during the combustion of the fuel,
– the net energy balance of fuels from vegetable oils is positive, which means that the solar energy stored in plant oil is considerably larger than that which is needed for its production,
– fuel from vegetable oils has an undeniably much smaller burden on the environment than fossil diesel because its combustion creates fewer climatically harmful substances (reduced emission of harmful exhaust gases by over 50 %, $CO_2$ – neutral, does not contain sulphur, phosphorous and lead, considerably reduced quantity of soot, reduced quantity of uncombusted hydrocarbons, CO and solid particles). In addition, it is much less toxic and has better biodegradability in water and the soil, and much better lubricating properties.

As raw materials for the production of biodiesel, cooking oils can be used, but these are available only in fairly small quantities. The main raw materials are the oils of oil crops from agricultural production, particularly the oil of oilseed rape, from which over 85 % of world production of biodiesel is derived.

In Croatia, the production of oil bearing plants and oil is not adequate even for the needs of the population and the animal husbandry industry, because they account for a small percentage of crops, of the low average yields, the lack of interest of the processing industry and small family farms, because the low economic effects from their production. Any more significant increase in the production of oil bearing plants for the needs of the non-food chain as well (for the production of biodiesel) can be attained by an increase in the areas devoted to these crops, on over 200 000 ha, which is made feasible by the resources in land and allowed by the requirements of the optimum rotation, and by an important increase in average yields (>30 %) by the introduction of contemporary technology. This would ensure sufficient quantities of oil and meal for the needs of food and animal husbandry, as well as raw materials for 90 000 to 100 000 tons of biodiesel.

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