Long-term sustainability of bio-components production

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Abstract

Biofuels play an increasingly important role in the motor fuel market. The list of biofuels (bio-components) in accordance with EU legislations contains a number of substances not widely used in the market. Traditionally these include fatty acid methyl esters (FAME, in the Czech Republic methyl ether of rape seed oil) and bioethanol (also ethyl terc. buthyl ether – ETBE, based on bioethanol). The availability and possible utilizations of bio-component fuels in Czech Republic and Serbia are discussed. Additional attention is paid on the identification of the possibilities to improve effectiveness of rapeseed cultivation and utilization of by-products from FAME production (utilization of sew, rape-meal and glycerol) which will allow fulfilment of the sustainability criteria for first generation bio-fuels. Comments on new approaches on renewable co-processing are presented. The concept of 3E (emissions, energy demand, and economics) is introduced specifying three main attributes for effective production of FAME production in accordance with legal compliances. The price change of bio-components is analyzed in comparison to the price of motor fuels, identifying a possible (speculative) crude price break-even point at the level of 149–176 USD/bbl at which point bio-fuels would become economically cost effective for the use by refiners.

Keywords: biofuels, EU legislation, crude oil price, bioethanol, FAME.

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Biofuels have become an important part of the motor fuel production portfolio throughout Europe, as well as across the world. Motivation factors for biofuels introduction are:

- The replacement of fossil fuels due to its availability as natural resource, import independency, reduction of GHG emissions (suspected to have impact on global warming), use of land in the developed countries due to over-production of agricultural food [1];
- EU legislations in practise throughout EU countries such as Directive 2009/28/ES aim to reach up to 20% renewable resources on total energy consumption and/or 10% in transportation share in the EU; each EU country applies a different target on share on total energy consumption (Table 1) [2] but all have set a goal at 10% in transportation;
- Sustainability based on criteria on GHG emissions.

MOTOR FUELS

EU Directive 2009/28/ES [2] defines the following renewable motor fuel components:

- bioethanol from sugar beans, wheat, corn/ /maize, and sugar cane;
- renewable sources part of ETBE (bio-MTBE);
- renewable sources part of TAEE;
- biobutanol;
- biodiesel (methyl ester of fatty acids from rape seed, sunflower, soybean, palm oil, waste vegetable or animal oil);
- hydrotreated vegetable oil (from rape seed, sunflower, palm oil);
- pure vegetable oil from rape seed;
- biogas from municipal organic waste or wet manure as compressed natural gas;
- farmed or waste wood Fischer-Tropsch diesel;
- farmed or waste wood DME;
- farmed or waste wood biomethanol.

The main biofuels/bio-components used in the EU are ethanol and FAME (mainly as rapeseed oil based). The biofuels are largely introduced in all European countries. It's worth mentioning that one of the first country to introduce the so-called "oleo-chemistry" program on a larger scale (resulting in production of FAME and biodiesel, among others) was the Czech Republic [3,4]. As early as the beginning of 1990s, the biofuel market share reached several percents of the total diesel fuel consumption in the Czech Republic [5,6]. At that time, the biodiesel production was significantly subsidized by the government, which sufficiently motivated producers to establish new productions and introduce product to the Czech market. In the

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Table 1. EU countries – share of renewable energy targets 2020 [2]

EU Country	2006 actual percent of renewable energy on total energy	2020 target percent of renewable energy on total energy
Sweden	40	49
Latvia	35	42
Finland	29	38
Austria	23	34
Portugal	21	31
Denmark	17	30
Estonia	18	25
Slovenia	16	25
Romania	18	24
Lithuania	15	23
France	10	23
Spain	9	20
Greece	7	18
Germany	6	18
Italy	5	17
Ireland	3	16
Bulgaria	9	16
UK	1	15
Poland	7	15
Netherlands	2	14
Slovakia	7	14
Belgium	2	13
Cyprus	2	13
Hungary	4	13
Czech Republic	6	13
Luxemburg	1	11
Malta	0	10

meantime, the European legislation was developed, transposed onto the national legislations of member countries resulting into mandatory use of bio-components for traditional motor fuels (according to EN 228 and 590) gradually eliminating, at the same time, the state supports. This resulted with the fact that refiners and car-users are bearing all the extra costs associated with renewable fuel production. The Czech Refining Company (major crude oil processing company in the Czech Republic and key refinery in the region of Central Europe) established the regular use of bio-components ever since 2004 [7–10] being associated with approximately 15 million EUR investment cost and price difference compared to traditional motor fuels based on crude oil processing [11]. The final decision, introduced in 2004 and in effect until now was to directly blend FAME (usually domestic origin based on rape seed oil) with diesel fuel and directly blend bioethanol (from different origins incl. domestic) with gasoline (taking into the account oxygen content limits and availability of domestic MTBE). The existing MTBE plant has not yet been converted into ETBE due to investment cost return issues and feasibility to produce gasoline of required quality while combining traditional gasoline components (based on crude oil), MTBE and bioethanol [11,12].

The situation in Serbia is such that the main crude processing company Petroleum Industry of Serbia (Nafta Industrija Srbije – NIS) does not have actual biofuels production. This is similar to most of refining companies in Europe (including the Czech Republic). It may take up to several years for refineries to decide to go into the business of biofuel production. There are 3 privately owned biodiesel production factory in Serbia: FAM Kruševac (capacity of 25,000 tonnes per year construction not completed). “Bioplanta” Bačka Topola (small capacity operated based on different vegetable and waste oils) and “Victoria Oil” Šid (not operated capacity of 100,000 tonnes per year). The Šid factory unit was built according to the Lurgi design. According to the Serbian energy plan, 10% e.e. of total fuel production by the year 2020 will have been comprised of those coming from renewable sources.

According to Directive 2009/28/EC [2] in the EU “Each Member State shall ensure that information is given to the public on the availability and environmental benefits of all different renewable sources of energy transport. When the percentages of biofuels, blended in mineral oil derivatives, exceed 10% by volume, Member States shall require this to be indicated at the sales points.” This regulation is being implemented by all EU countries (including the Czech Republic) and is going to be implemented in the Republic of Serbia as well.

Price and cost aspects

The motivation of bio-component use for refiners is influenced by pricing of bioethanol and FAME. The historical price difference is described in Figure 1.

The historical price development shows that FAME is usually traded at a price higher than ultra-low-sulphur diesel (ULSD) by 300–500 USD/t, while bioethanol has its own price development which has recently been independent of the price of unleaded gasoline 95 (UNL95). It could be concluded that the FAME price settlement is based on the quoted diesel price plus margin, while the price of bioethanol is more driven by production cost (mainly raw material such as wheat, corn etc.) becoming at times (but rarely) cheaper (per ton) than gasoline (note 07/2008, 08/2009, 06/2010, 05/2011 on Figure 1). This does not mean that bioethanol is a more effective fuel, due to a much lower energy content (respectively heating energy of ethanol which is approx. 60% comparing to gasoline) [12–14].

Comparing the crude price (and refining products), the change of bio-component price is seen as the ratio between FAME and diesel that was between 1.25 and 2.00 (multiple of quoted diesel price) with average ratio of 1.65. In case of bioethanol/gasoline, the historical range was between 0.9 and 3.0 (multiple of quoted gasoline price) with an average ratio of 1.30. The above-mentioned conclusion on the break-even price of crude oil is derived from this rough analysis taking into account that the historical ration of diesel/gasoline to crude oil (Brent based) is 1.30–1.35.

The break-even point of crude price (supposing constant price development of bio-components and proportional approach to pricing fossil fuels and current ratios of fossil fuels and bio-components) is estimated at 149 USD/t for biodiesel/diesel and 176 USD/t for bioethanol/gasoline (all based on energy equivalent). The historical crude oil price change can be seen in Figure 2.

“3E” CONCEPT

As in many other cases, the “3E” concept could be applied for evaluation of biofuels effectiveness [13]. This concept is taking into account a balance approach to the three main attributes applied in the modern industry: **E**mission impact, **E**nergy demand and **E**conomics/General Effectiveness of the production. All three attributes are contributing to the economic, commercial, technical (including environment impact) and legislative aspects from the point of suppliers (in our case bio-components), producers (in our case refiners), public stakeholders (like EU and national governmental au-

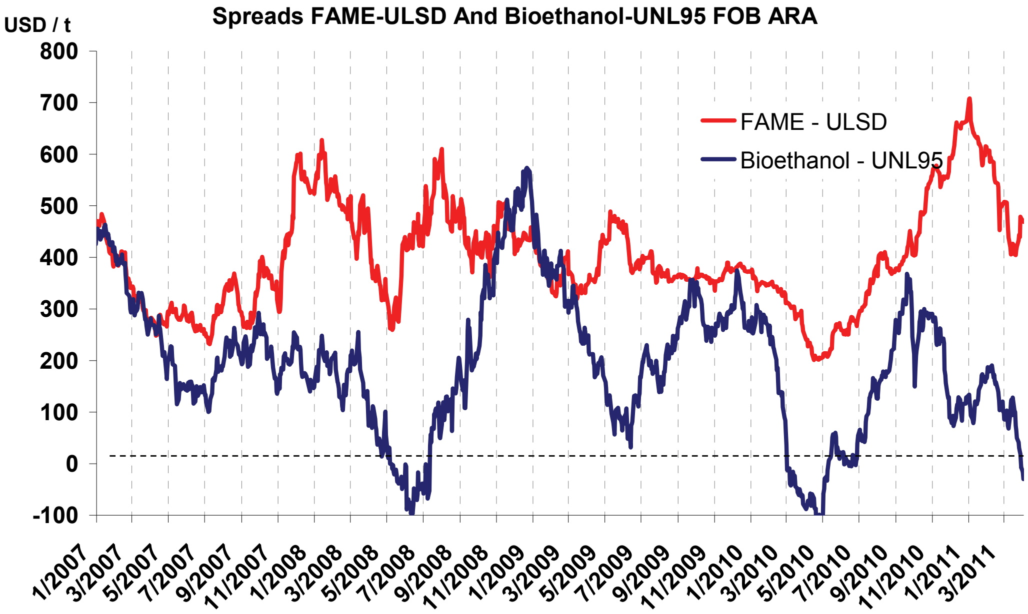

Figure 1. Price difference FAME – ULSD and bioethanol – UNL95 in the period January 2007–March 2011. Source: based on Platt’s database [13,14].

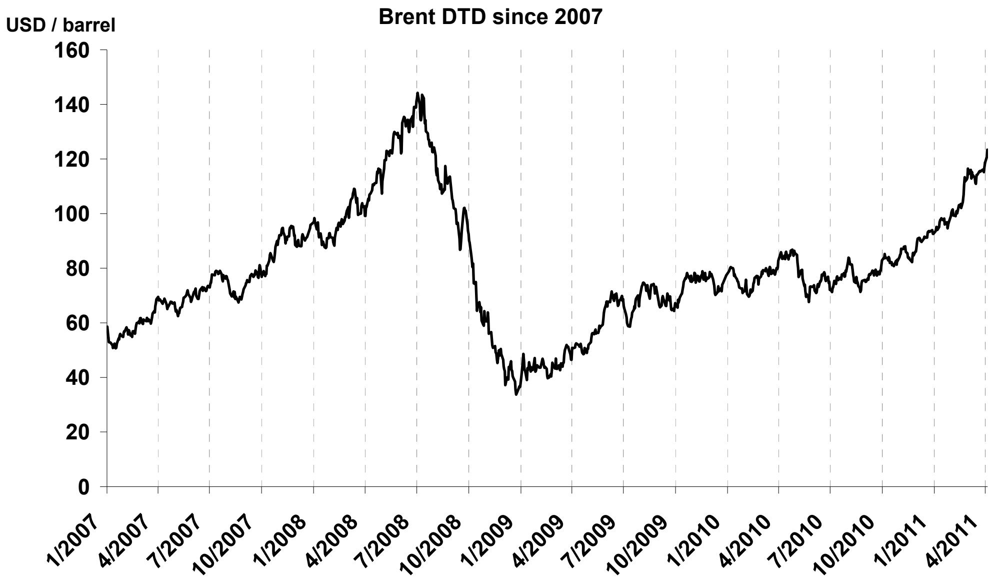

Figure 2. Crude price change over the period 2007–2011. Source: based on Platt's database [13,14].

thorities, environment authorities, public as in car drivers/users, etc.). The 3E concept is very important in particular to the first generation biofuels. It is justified that utilization of bioethanol and especially FAME can significantly reduce crude oil use and reduce greenhouse gas emission.

Even though ethanol production has for decades mainly depended on energy crops containing starch and sugar (corn, sugar cane, etc.), currently, new technologies for converting lignocellulosic biomass into ethanol (second generation biofuels) are under development. The use of lignocellulosic biomass, such as agricultural residues, forest and municipal waste, for the production of biofuels will be unavoidable if liquid fossil fuels are to be replaced by renewable and sustainable alternatives [15] and definitely will contribute to 3E.

The traditional methods of ethanol production (as the first generation approach) are not the subject of detailed analysis presented in this article, but rather the energy balance and greenhouse gas (GHG) emissions that are the issues in the traditional fuel production. This will be further analyzed at the FAME production selected reference units located in the Czech Republic.

Based on the FAME production in the Czech Republic with capacity of 100,000 tonnes per year the particular emission and energy impact were calculated. Results are provided in Tables 2 and 3. Complete production life-cycle is considered, e.g. rapeseed growth – oil production – FAME production – logistics [3].

Reduction of GHG emissions compared to reference fossil fuel is 45.8%, hence most of the emissions are (surprisingly) allocated to the agricultural activities (mainly fuel consumption, fertilizers use).

Table 2. Total emission of GHG in FAME production life-cycle [3]

Production phase	Emission g CO_2 eq/kg	Emission g CO_2 eq/MJ	Share %
Rape seed growing	1073	29.0	64
Oil production	203	5.5	12
FAME Production	367	9.9	22
Logistics	37	1.0	2
Total	1680	45.4	100

Table 3. Total energy balance of FAME production and use life-cycle [3,13]

Input	GJ/t	Output	t/t	GJ/t
Rape seed growing	14.1	FAME	1.00	37.0
Oil production	3.7	Rape meal	1.50	22.9
FAME Production	3.2	Glycerine, 80%	0.12	1.5
Total	21.0	–	–	61.4

Table 2 shows the energy balance of the total life cycle of FAME production (*e.g.*, consumption of energy required for plant growing, seeds harvesting, seeds processing, FAME production, and including other cost like distribution versus energy gained by using FAME as motor fuel component, and possibly use of by-products and production wastes) with the reference to real FAME production unit mentioned above.

As a result of the energy balance, 0.34 GJ is consumed for 1 GJ of energy gained, *e.g.*, energy demand is 34% ("well to wheal" – WTW concept).

Improvement of effectiveness of biofuels is connected with the whole production life cycle (e.g. not only to FAME production; so called "well to tank"– WTT concept), which covers original raw material, technology for biofuel production, effectiveness of biofuels use in engines and possible utilization of by-products.

Opportunities for improvement of effectiveness of FAME production

As already mentioned, the main energy consumption for whole biodiesel cycle is allocated on growing of rapeseed. This could be improved by:

- use of used vegetable oil (eliminate production of seeds and “fresh” oil);
- increase of yields of rapeseed harvest (improve effectiveness of agricultural treatment);
- use of straw (use waste material for energy production);
- improvement of technology for FAME production;
- possible use of by-products from FAME (possibly also oil) production.

Rape seeds replacement with the use of vegetable/animal oils

Utilisation of used vegetable/animal oils in practice will replace the need of “fresh” seeds and “freshly” produced oil, and consequently would contribute to eliminating the costs of growing the rape seeds thus transferring the actual production costs to the oil production itself. The total emission will decrease from 45.5 to 12 g CO_2 eq./MJ. GHG emission saving compared to fossil fuel will increase from 45.8 to 85.0%. Use of used vegetable/animal oils eliminates energy consumption for rape seed growing, decrease energy consumption for oil processing and treatment but does not allow to use energy from sew. Total energy consumption will be 48.5 GJ/t. Energy demand will decrease from 34 to 8% [3,13].

Increase rapeseed harvest yield

The main contributors of GHG emissions in the phase of rape growing are: fertilizers (70%), motor fuels (20%) and other sources (10%). The efficiency could be improved by the increase in rapeseed yield and use of sew [3]. The harvest yield in the climatic conditions of the Central Europe could be increased from 3.1 t/ha (average yield in the Czech Republic) to 3.6 t/ha (average yield in Germany) contributing to GHG emission reduction by 4.6 g/MJ (increasing efficiency of GHG saving to 51.3%) and improving energy demand by 16% [3,13]. Increase of efficiency of harvest eliminates energy consumption for rapeseed growth while the additional energy could be used for straw. The total energy saving is 2.2 GJ/t resulting in a total energy demand decrease from 34 to 30% [3,13].

Use of straw

The estimated calculations of GHG emissions do not contain possible use of straw (with possible yield up to 5.4 t/ha) [13]. Straw could be used as ecological fuel or raw material for production of second-generation biofuels. In case of use of rape straw, the part of emission (50%) in the phase of growing could be allocated to straw (14.5 g CO_2 eq./MJ) [3]. The use of straw will contribute to decrease GHG emissions of FAME production from 45.4 to 30.9 g CO_2 eq./MJ. Full use of straw as by-product contributes to total energy demand decrease from 34 to 17%, and may significantly improve economics of FAME production [3,13].

Improvement of FAME production technology

The current technological processes for production of vegetable oils and their etherification by methanol are on a relatively high level. However, contribution to GHG emission savings is still insignificant although some efficiency improvement could be expected (new catalyst, especially heterogenic, further improvement of energy balance of existing production units, simplifycation of treatment of FAME and glycerine phases, etc.) [3,13].

Use of by-products

Significant secondary effects to 3E improvement might be achieved with optimal use of by-products, as follows [3]:

- use of rape-meal for heat and electric energy production;
- gasification and pyrolysis of rape-meal;
- larger chemical use of glycerine.

This use will not have the direct impact effectiveness of FAME production itself but will contribute to GHG emissions decrease and energy savings by further processing.

Use of by-products – use of rape-meal for heat and electric energy production

Rape-meal is commonly used as proteinic feedstuff for animals. In case of its surplus, it could be used for energy production also. Rape-meal could be burnt separately or together with “classic” fuels like coal (participating at several subsidization programs applied in most of EU countries). Due to content of sulphur and nitrogen (proteins) flue gases should be de-sulphurised and possibly de-nitrified. Rape-meal energy content is 15.3 GJ/t [3].

Use of by-products – gasification and pyrolysis of rape-meal

Rape-meal could be used for production of syn-gas by its gasification or pyrolysis and consequently for production of hydrocarbon fuels. Due to the fact that such processes are already applied in petrochemical and/or refining industry at large scale, the combined processes should be taken into consideration, as some recent reference research activities in the Czech Republic aimed to co-pyrolysis of brown coal and rape-meal [16] and partial oxidation of mixture of vegetable (rape) oil with liquid (crude oil based) hydrocarbons show [17,18].

It was demonstrated by experimental testing [16] that co-pyrolysis of brown coal and rape-meal jointly can bring process improvements in many areas: lower appearance of coke, higher yield of pyrolysis oil, and higher yield of aliphatic hydrocarbons.

Another process – partial oxidation of vegetable and crude oil-based liquids [17,18] and suspension of crude oil-based liquids with rape-meal was studied in laboratory and pilot plant scale with the objective to propose feasible solution for the improvement of 3E by co-processing of the wastes and by-products formed during biofuels production. Biomass "gasification" (by partial oxidation by oxygen in presence of steam) is a way to utilize energy content of biomass and in the same time to create/produce raw material for consequent chemical synthesis (in this case H_2 and CO).

Use of by-products – chemical valuation of glycerine

Glycerine could be the basic raw material for number of chemical substances, including motor fuel components [3]. Production of glycerine has sharply grown together with wide development of biodiesel (its market price has, at the same time, significantly decreased) [13]. Typical products derived from glycerin are:

- di-hydroxy acetone;
- 1,3-propandiol by biochemical route [19,20];
- 1,2-propandiol, iso-propanol (usable also as motor fuel likewise bioethanol or biobutanol) by hydrogenation;
- tri-, di- and mono-isobutyl ether of glycerine (as diesel component) by etherification; of glycerine and iso-butylene (similar to the principles of the synthesis of MTBE and/or ETBE process).

All these products produced the "bio-way" could replace traditional synthesis from classic raw materials by routine technologies based on hydrocarbons derived from crude oil (such as propylene, butane, etc.).

Optimal use of glycerine depends, of course, from number of process related factors like real yields, energy and material balance, robustness of technology, etc. The best glycerine derivatives synthesis results are achieved when minimal molecule reduction (elimination of de-hydratation, de-carbonisation) and/or molecule growth is achieved [14] (Table 4).

Final remarks

The FAME producers in EU are mainly oriented to the core product and utilization of by-products and wastes are not yet implemented in practice. Long-term sustainability of the first generation biofuels will be feasible only in case of improvement of their production effectiveness.

The energy and refining sector are partly subsidized to use renewable raw materials for energy and motor fuels production. Another sector, the chemical industry, with the utilization of biofuels by-products, could be the next target for the improvement of general 3E conceptual position and, as such, be considered for renewable sources utilization support similar to energy and refining sectors [21,22].

Table 4. Use of by-products – chemical valuation of glycerine [13,14]

Derivative	Molar mass g mol^{-1}	Theorical yield %
Glycerine	92	
Propandiol	76	83
Isopropanol	60	65
Dihydroxy acetone	90	98
Mono-isobutyl ether	148	160
Di-isobutyl ether	204	222
Tri-isobutyl ether	260	283

Comparing the crude price (and refining products) development with bio-component price change, the average ratio between FAME and diesel was 1.65. In case of bioethanol versus gasoline the historical range was at average 1.30. This confirms and shows current demotivation of the refiners to use bio-components indicating break-even points of crude oil price at around 180 USD/bbl for bio-components economic "attractiveness".

CONCLUSIONS

The bio-components are definitely contributing to total motor fuels balance and to reaching the renewable energy use targets defined by EU Commission and Parliament. The goal of reaching 10% e.e. in 2020 is respected by all EU countries (including the Czech Republic) and it is expected to be introduced to Republic of Serbia as well.

The several views are considerable:

- Economic view: more effective production of bio-components may bring more acceptable pricing for refiners;
- Commercial view: larger product portfolio could be more preferable by refiners;
- Technical view: diversification of component quality could contribute for improvement of refining product quality;

Legislative view: EU countries bio-legislation might be unified in accordance with EU standards being fully accepted by the bio- and refining sectors.

Used abbreviations

bbl	Barel (volume unit used for crude oil, approx.159 liters)
Brent DTD	Forward price of crude "dated" Brent-Forties-Oseberg-Ekofisk according its physical deliveries for next 10-23 days in parity FOB

DME	Di-methyl ether
EU	European union
ETBE	Ethyl terc. buthyl ether
EtOH	Ethanol (usually bio)
FAME	Fatty acid methyl ether
GHG	Green-house gases (mainly CO_2)
MTBE	Methyl- terc. buthyl ether
TAEE	Ethyl-terc.amyl ether
ULSD	Ultra low sulphur diesel (sulphur content below 10 ppm)
UNL 95	Unleaded gasoline with octane number 95
USD	American dollar
WTT	“Well to tank”, analysis of motor fuel impact (cost, emissions etc.) for cycle: exploration to production (usually crude exploration or growing of agricultural raw material, crude or other feedstock transportation, crude or other feedstock processing)
WTW	“Well to wheal”, analysis of motor fuel impact (cost, emissions, etc.) from exploration to final use (*e.g.*, WTT Combined with effects from fuel in the car, usually heating value, CO_2 emissions etc.)

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IZVOD

DUGOROČNA ODRŽIVOST PROIZVODNJE BIOKOMPONENTI

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Biogoriva igraju sve važniju ulogu na tržištu motornih goriva. Lista biogoriva (biokomponenti) u saglasnosti sa EU legislativom sadrži brojna jedinjenja kojih nema u velikoj meri na tržištu. Uobičajeno, one sadrže metil ester masnih kiselina (FAME, u Češkoj Republici, metil etar uljane repice) i bioethanol (takođe etil tercijarni butil etar – ETBE, baziran na bioetanolu). U radu su razmotreni raspoloživost i moguća primena biokomponentnih goriva u Češkoj i Srbiji. Posvećena je posebna pažnja na identifikaciji mogućnosti poboljšanja efektivnosti uzgajanja uljane repice i iskorišćenju nusprodukata proizvodnje FAME (repičinog brašna i glicerola) što bi obezbedilo ispunjenje kriterijuma održivosti za prvu generaciju biogoriva. Komentarisani su novi pristupi obnovljivog koprocesiranja. Koncept 3E (emisije, energetski zahtevi i ekonomika) uvedeni su specificiranjem tri glavna atributa za efektivnu proizvodnju FAME, u skladu sa pravnom usaglašenošću. Promena cene biokomponenti analizirana je u poređenju sa cenama motornih goriva, identifikujući moguću (spekulativnu) prelomnu tačku pri ceni sirove nafte od 149–176 USD/bbl, kada bi biogoriva postala ekonomski isplativa za primenu u rafinerijama.

Ključne reči: Biogoriva • EU legislativa • Cene sirove nafte • Bioetanol • FAME