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Potential of Greenhouse Gas Reduction Producing and Using Biodiesel from Fatty Waste

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Resolution of climate change, economy and energy decentralization problems is related to development of biofuel use and production. An increase in biofuel use and production is to ensure the reduction in greenhouse gas emissions. Following a life cycle method comparative analysis of rape methyl ester and diesel before their use in diesel engines has indicated that in production of rape methyl ester the growing of rape seeds consumes 56% of energy whose expenditure is directly dependent on rape productivity. In order to decrease energy expenditures the use of fatty waste is expedient. It is determined that production of biodiesel from frying fats yields 1.37 MJ and 98.15 g $CO_{2eq.}$ economy for one MJ of product compared to diesel. Potential of used fats methyl ester greenhouse gas reduction in the life cycle reaches 0.87 and is 27% greater that that of rape methyl ester. Used fats methyl ester meets balance criteria therefore in our country the waste collection system from food industry and catering enterprises is to be established.
Key words*: sustainability criteria of biofuels, life cycle, rape methyl ester (RME), biodiesel, fatty waste, greenhouse gas.*

1. Introduction

Sustainable development is a long-term EU startegy ensuring clean and healthy environment and improving the life quality to future generations. With the growth of economics an increase in the use of natural resources and environment pollution is persued to be either slower than that of economics or to stop increasing.

Following the principle of sustainable development strategy change harmful materials to environment and health are to be replaced by harmless, the exhausting resources – by renewable. In transport the renewable energy source is biofuel. Globally, transport sector consumes about 40% of fossil energy resources, therefore biofuel development is an attractive alternative to conventional. Burning of excavated energy sources raises environment pollution, expedites climate warming which is causing natural disasters. The use of renewable energy source comes not only in assistance to solve climate change problems, but allows combat poverty and the problems of economy and energy decentralisation.

One of the tasks of renewable energy resources development is to increase the use of renewable and other sources (waste) in transport ensuring that their production and application all over the world should have a positive effect on the environment. Consumption of biofuel and its share produced by processing the waste compared to the total fuel amount used in transport is one of the indicators of sustainable economy development.

Directive 2009/28/EC of the European Parliament and of the Council on promotion of the use of energy from renewable sources in transport (further Directive 2009.28/EC) actually sets the twofold higher index of minimal biofuel compulsory consumption. Directive 2009/28/EC schedules that the share of renewable energy sources in the final energy consumption in Lithuanian by 2020 shall reach 23%, while in other countries from 10% (Malta) to 49% (Sweden). To avoid a negative impact of biofuel production on the environment, biofuels and bioliquids produced in the EU and imported to it have to meet the sustainability criteria related to the reduction in the amount of greenhouse gas emissions, agriculture and the environment.

One of sustainability criteria is reduction in the amount of gases causing a greenhouse effect. The Directive envisages that this amount due to the use of biofuels and bioliquids shall be reduced by 35% up to 2017 (this index will be increased to 50% by January 2017, and by January 2018 it will be increased to 60% to the systems where production will start in 2017 and later).

To implement the Directive requirements, in our country the greenhouse gas amount is being reduced in two separate directions. Diesel may be best replaced by rape methyl ester (further RME), petrol – by bioethanol. In Lithuania biodiesel is produced from rape oil. Rape is one of the main oil plants grown in Europe and it is most common raw material used for biodiesel production Methyl ester obtained during oil esterification has similar properties to fossil diesel fuel.

In 2009 biodiesel production achieved 23.5 million tons per year: in Germany – 5.2 m. t. per year, in France – 2.5 m. t. per year, in Italy – 1.9 m. t. per year. In 2009 in the EU about 9 m. t. of biodiesel were produced of rape and fatty waste, by 2010 it is planned to produce about 22 m. t. of biodiesel. In 2009 in Lithuania there were produced 98 ths tons of biodiesel (about 5% of general fuel consumption). By 2010 its production is planned to achieve 147 ths tons. (in the period of 2009-2010 the EU biodiesel industry restrained its growth).

Production of biofuels (RME and bioethanol) is in a full swing in Lithuania, nevertheless it has not achieved the planned extent. The national strategy of renewable energy sources development (further-national strategy) sets out to increase the renewable energy resources share compared to the final consumption in all sorts of transport from 4.3 per cent in 2008 to 10 per cent by 2020.

To comply with the biofuels index planned in Directive 2003/30/EC of the European Parliament and of the Council and that in the national strategy it is necessary to increase the compulsory percentage of RME blend in diesel fuel and reduce biofuels cost price. According to the experience of EU countries one of the means of reducing biofuels cost price is the use of fatty waste in their production.

According to the EU normative documents an increase in biodiesel use and production must be followed by reduction in greenhouse gas emission. Using one or the other fuel in internal combustion engines it is possible to decrease their harmful effect on the environment, however, industrial and transport processes may significantly pollute the atmosphere. To evaluate comprehensively economic-ecological fuel characteristics and to determine important problems related to reduction in greenhouse gas emissions and energy expenditures in any stage of a product is possible by the method of life cycle (LST EN ISO 14044:2007). Researchers (Bernard & Prieur 2007; Bernesson et al. 2004; Hammond et al. 2008; Guine et al. 2009; Janulis 2004; Yan & Crookes R. 2009; Reijnders et al. 2008; Tsoutsos et al. 2010; Takahashi 2010) frequently apply the life cycle method to evaluation of biofuels.

The aim of this study is to evaluate the options of greenhouse gas emissions reduction in fuel in diesel engines using biodiesel produced from fatty waste during its whole life cycle.

2. Research methods

The life cycle evaluation model described by SETAC (SETAC 1993) has been taken in this research. The life cycle consists of three components (Caluwe 1997): life cycle inventory, lifecycle effect analysis, life cycle perfection analysis. The life cycle is usually divided into three phases: production phase, usage phase and utilization phase. Transport use aspect is given as a separate phase or included in them.

According to this method the effect of a product on the environment is calculated considering inputs and outputs which later are converted into effects or damage to the environment. Inputs of life cycle are raw materials used for production, fuel, energy, technological transport, utilization processes. Outputs of life cycle are emissions into water, atmosphere, soil, waste formation.

In calculations of the energy expenditure for producing these types of fuel we referred to average values of energy expenditures in the EU and Lithuania (Zah 2007; LITBIOMA, 2008;). Energy expenditures were expressed in 1 MJ of a product. In the production phase only the gas emission affecting the climate was evaluated (CO_2, CH_4, N_2O, NO_X). Their effect on the climate was equalized to CO_2 gas effect expressed as $CO_{2eq..}$according to emissions recalculation methods suggested by the intergovernmental panel of Climate Change (IPCC 2007) for the period of 100 years (1 g CO_2 = 1 g $CO_{2eq..}$; 1g N_2O – 310 g $CO_{2eq..}$; 1g CH_4 – 21 g CO_{2eq} , 1 g NO_x =8 g $CO_{eq.}$).

Carbon dioxide emission after burning of the fuel in a diesel engine is calculated according to formula (Smailys, 1994):

$$m_{CO2} = 3.67 \text{ kg C} / 1 \text{ kg fuel} \quad (1)$$

here:
C - carbon mass share in the fuel.

Carbon dioxide equivalent of electricity or heat consumption for producing fuel is calculated according to formula (Covenant of Mayors., 2010):

$$m_{CO2eq} = Q \times E_f \quad (2)$$

here:
Q - quantity of natural gas consumption (kWh);
emission factor for electricity or heat consumption (g CO_{2eq} / kWh)

The greenhouse gas emissions are calculated as MJ of produced energy. Greenhouse gas reduction potential is calculated according to formula (Directive 2003/30/EC V Appendix):

Reduction potencial = (EF – EC)/EF (3)

here:
EC - total emissions $CO_{2eq.}$ from the biofuel or bioliquid;
EF – total emissions $CO_{2eq.}$ from fossil fuel comparator.

3. Comparable analysis of the life cycle of greenhouse gas of diesel and rape methyl ester

In order to evaluate an option of using fatty waste for biodiesel production without increasing energy expenditures and reducing greenhouse gas emissions, the life cycle of RME before its use in diesel engines has been explicitly analyzed comparing to diesel produced from fossil fuel.

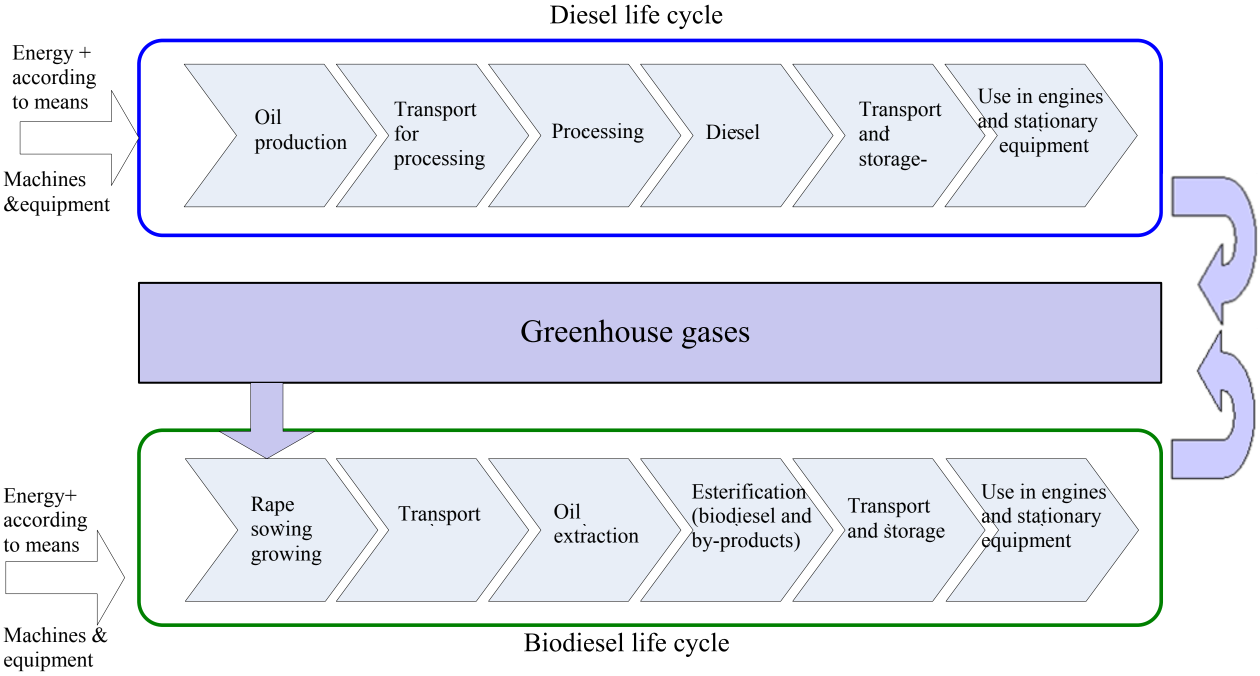

Fig. 1. Life cycles of diesel and biodiesel

RME is a natural product possessing the life cycle from the origin (sowing) of rape to its demise. According to this method the impact of this product is calculated with respect to inputs and outputs which later are transformed into effects or harm to the environment. Inputs of the life cycle are raw materials for production, fuel, energy, technological, transport and utilization processes. Outputs of the life cycle are emissions to water, atmosphere, soil, waste formation. According to this method one of the main evaluation indices of the biodiesel life cycle is greenhouse gases emissions. Scheme of diesel and biodiesel life cycle is presented in Figure 1.

RME is obtained from renewable raw material – rape. During rape growth energy is used to plough the soil, to sow, to harvest and to transport it. All this work is done by agricultural machines whose fuel is oil products which after burning emit gas. Our calculations indicate that during this process agriculture emits 66% of gases affecting our climate. (Fig. 2). The other part of energy is used for oil extraction, transporting to gas stations.

Production of RME releases by-products – oil cake and glycerol, the latter is used in chemical industry and may replace synthesized from oil glycerol. Rape oil cake is rich protein supplement (1kg = 17.5 MJ) its composition is close to soy protein.

To fully reflect the life cycle of biodiesel and diesel, we must estimate how much energy emissions would be used for production and transportation of soybean meal, synthetic glycerol and also greenhouse gas that separate in the processes. Life cycle of soybean meal and synthetic glycerol we included into the life cycle of diesel fuel cycle.

Comparative analysis of the life cycle of biodiesel and diesel not used in diesel engines (Fig. 2) has indicated that production of 1 MJ biodiesel consumes 0.7 MJ of energy, while the climate gases emission achieves 32.5 g $CO_{2eq.}$, i.e. 72. 4 % lower than that of diesel.

In the production of RME most of the energy (56%) is consumed by growing rape seed. Energy expenditures of RME life cycle calculated and presented in Fig.2 directly depend on rape productivity.

In accordance with data of the Lithuanian Department of Statistics in 2005-2009 amounts and productivity of rape grown in Lithuania vary (Table 1).

Statistical data indicate that rape productivity over the period of five year (2005-2009) has on the average achieved 1.8 t/ha. Consumption of 1 MJ of fossil energy for less than 2.0 t/ha rape productivity produces less than 1 MJ of RME energy (Janulis, Makareviciene 2000). The calculations indicate that it is an essential requisite to seek the means of reducing the energy expenditures which should not increase greenhouse gas emissions. One of the alternatives of using fatty waste for biodiesel production is being analyzed further on.

Table 1. Areas, crops and productivity of rape growing

	2005	2006	2007	2008	2009
Crops(ths. ha)	109.4	150.8	174.4	27.5	32.5
Yield (ths. t)	201.2	169.6	311.9	53.8	74.8
Productivity (t/ha)	1.84	1.12	1.79	1.96	2.3

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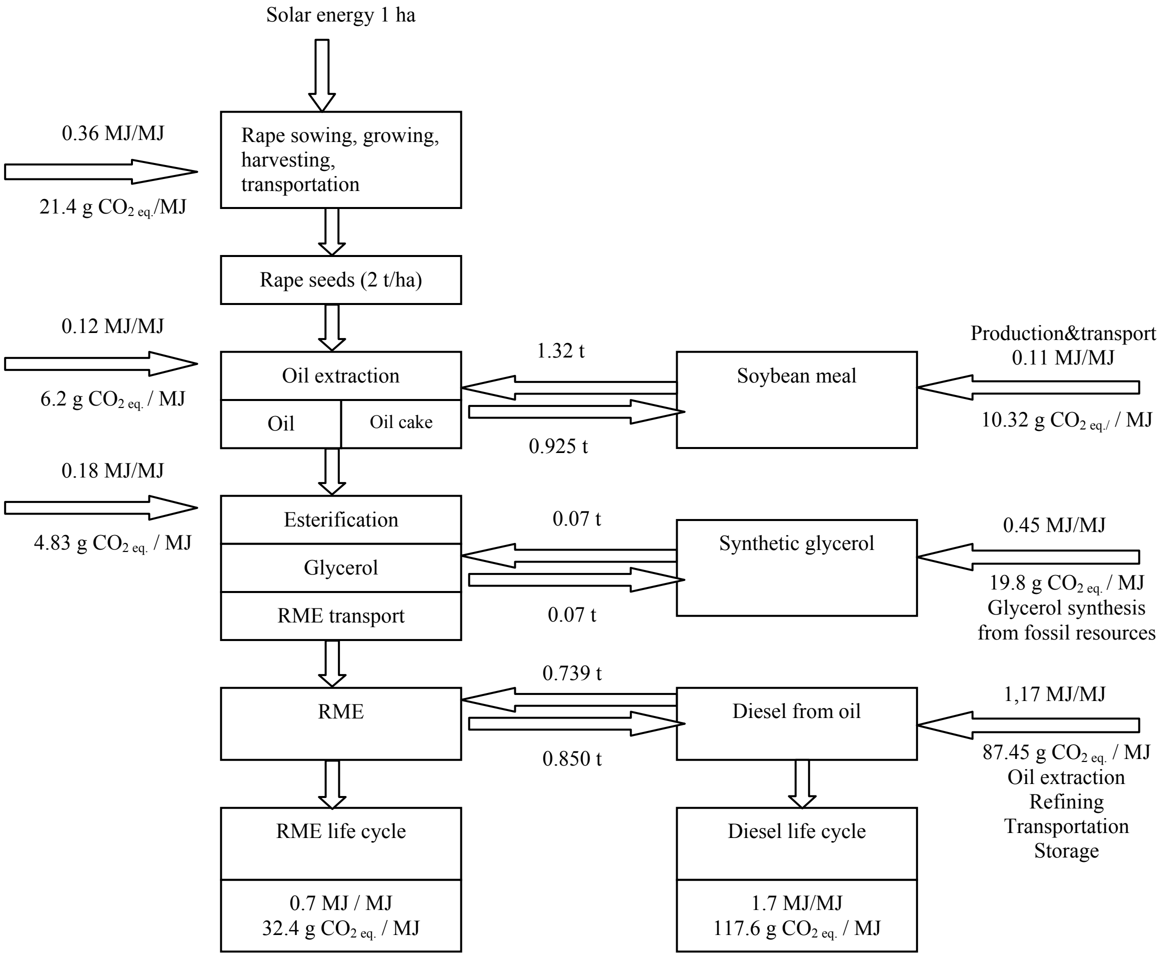


Fig. 2. Comparison of life cycles of RME and diesel fuel before using them in motor engines

4. Estimation of biodiesel production from fatty waste

Catering enterprises usually turn out fatty waste. Fatty wastes are biologically disintegrating: under the impact of microorganisms: they decompose emitting methane, carbon dioxide, sulfurate hydrogen, mercaptans, etc. Harmful compounds contaminate water, soil, atmosphere and greenhouse effect is caused.

The amounts of fatty waste vary. The amount of used fat is dependent on consumption of pure oil. Following the data of the Environment Protection Agency in Lithuania the annual waste amounts to 8000 t which nowadays is not processed. EU countries approximately generate annual amount from 0.7 to 1 million tons of used fats (Kulkarni & Dalai 2006). In Austrian households they say to cumulate about 3 l of used oil per year. Fast food restaurants McDonalds generate about 1000 l of fatty waste per month (Amt der Steiermärkischen Landesregierung 2010). The used fat amount depends on the number of people and the number of catering enterprises. In EU countries there is 1.4 restaurant per 1000 inhabitants **(**Canakci 2008**).** Similar tendency may be in our country, too.

Used fat is collected from different sources, therefore their chemical composition is variable (Phan A. N. & Phan T. M. 2008)

Acid composition of fat presented in Table 2 depends on the type of oil or animal fat.

Fuel elemental composition has a direct impact on CO_2, SO_x emission and insignificantly influences NO_x, particles emissions (Smailys 1994), therefore elemental composition of RME used for frying and diesel is compared (Table 3). Research literature review has indicated that elemental composition of used fats is close to that of RME.

Price of used fat is from 0.20 to 0.44 $ for 1 kg of fatty waste **(**Canakci 2008**).** Frying fat is 2-3 times cheaper raw material compared to vegetable oil (Zhang, Dube, McLean, Kates 2003).

Hydrolysis and oxidation reactions take place in frying vegetable oils used in industry and households. These processes both trigger changes in oil chemical and physical properties as well as in its composition. When frying oil acquires dark colour and distasteful smell, its viscosity and acid number grow up (Janulis 2005).

One of the suggested technological biodiesel schemes is given in Figure 3. Waste fats unlike rape oil have to be specially prepared before using them in biofuel production: they have to be filtered, separated, neutralized (Fig 3). The amount of free fatty acids and water in raw materials is the basic criterion according to which a transesterification process is chosen. If acidity of fats is higher than 1% before traditional alkaline reesterification , the esterification process is to be applied using acid catalyst H_2SO_4 (Math et al. 2010).

Many research papers indicate that energy value of biodiesel produced from fatty waste is lower than that of diesel or RME (Table 4).

Table 2. Acid composition of oil and animal fat (Singh, Singh, 2010; Dias et al. 2008)

FATTY ACID	FATTY ACID COMPOSITIONS (WT.%) OF VEGETABLE OILS AND FATS						
	Rape	Sunflower	Linseed	Olive	Pork lard	Beef lard	Poultry fat
Myristic	0	0	0	0	1.3	2.73	0.57
Myristoleic	0	0	0	0	0	0.5	0.26
Palmitoleic	3.5	7.3	7.3	5.0	23.7	22.99	22.76
Palmitoleic	0	0	0	0.3	2.2	2.86	8.37
Stearic	0.9	1.9	1.9	1.6	12.9	19.44	5.36
Oleic	64.1	13.6	13.6	74.7	41.4	41.60	42.07
Linoleic	22.3	77.2	77.2	17.6	15.0	3.91	17.14
Linolenic	8.2	0	0	0	1.0	0.49	1.07
Stearidonic	0	0	0	0.8	0	0.36	0.22
Arachidic							
Gadoleic							

Table 3 Comparison of fuel elemental composition

Title of fuels	Elemental composition, (%)			
	C	H	O	S
Diesel	87	13	0	< 0,05
Rape methyl ester	77.2	12.0	10.8	0
Frying fat methyl ester (Tomasevic 2003)	77.4	12.1	10.5	0
Frying fat methyl ester (Alcantara 2000)	77.0	12.0	11.0	0

Table 4. Energy values of fuels

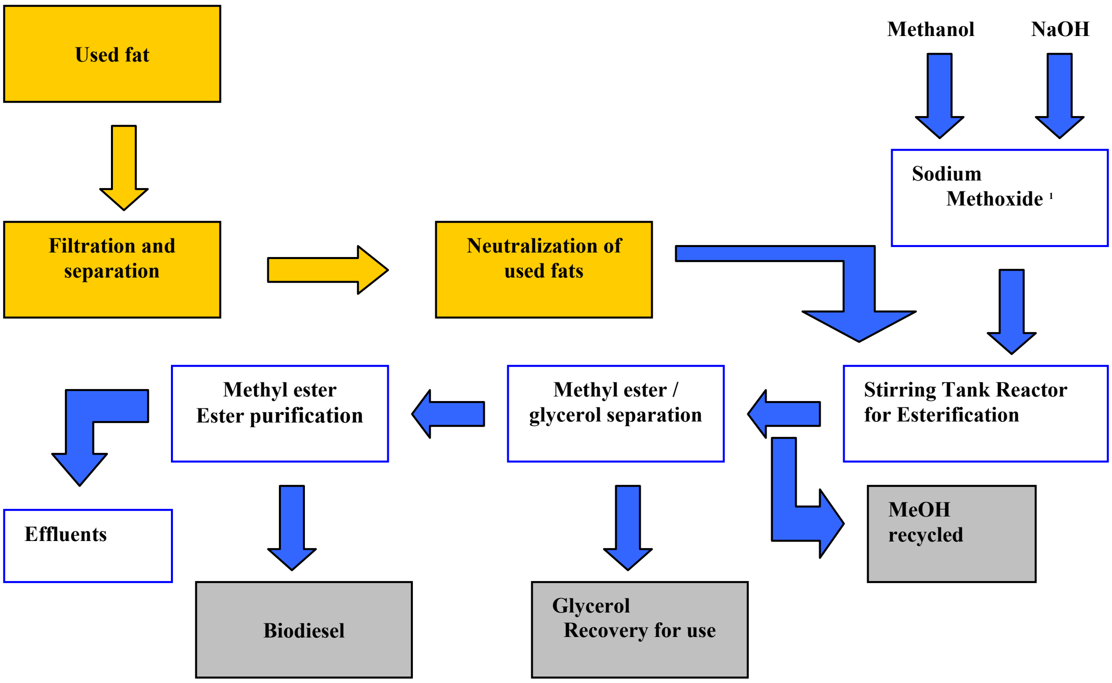
Fuel type	Density kg/l	Energy value according to mass (lower fuel calorific value MJ/kg) *	Energy value according to volume (lower fuel calorific value MJ/l) *
Diesel	0.84	42.8	35.95
Rape methyl ester	0.888	37.2	33.03
Used fat methyl ester	0.888	36.8	32.68

** Zah 2009*

Production of RME releases by-product – glycerol, the latter is used in chemical industry and may replace synthesized from oil glycerol. Life cycle of synthetic glycerine we included into the life cycle of diesel fuel cycle (Fig. 4)

Having analyzed the aspects of biodiesel production we have constructed the life cycle of used fat methyl ester and presented it in Figure 4. During the production of biodiesel from fatty waste greenhouse gases accumulate when collecting and transporting fats and processing waste.

Comparison of the state cycles of diesel and fatty waste methyl ester (Fig.4) has shown that production of biodiesel from frying methyl ester economizes 1.37 MJ energy and 98.15 g $CO_{2eq.}$ for one MJ of product. Comparative analysis of RME and used fats methyl ester indicate that production of used fats methyl ester economizes 0.45 MJ energy and 23.3 g $CO_{2eq.}$ for one MJ of product.



Pre-treatment needed for the transesterification of used fats

Products obtained during the process

[1] – The catalyst more used are KOH and NaOH

Fig. 3. Technological scheme of biodiesel production from frying fat (Leung 2001).

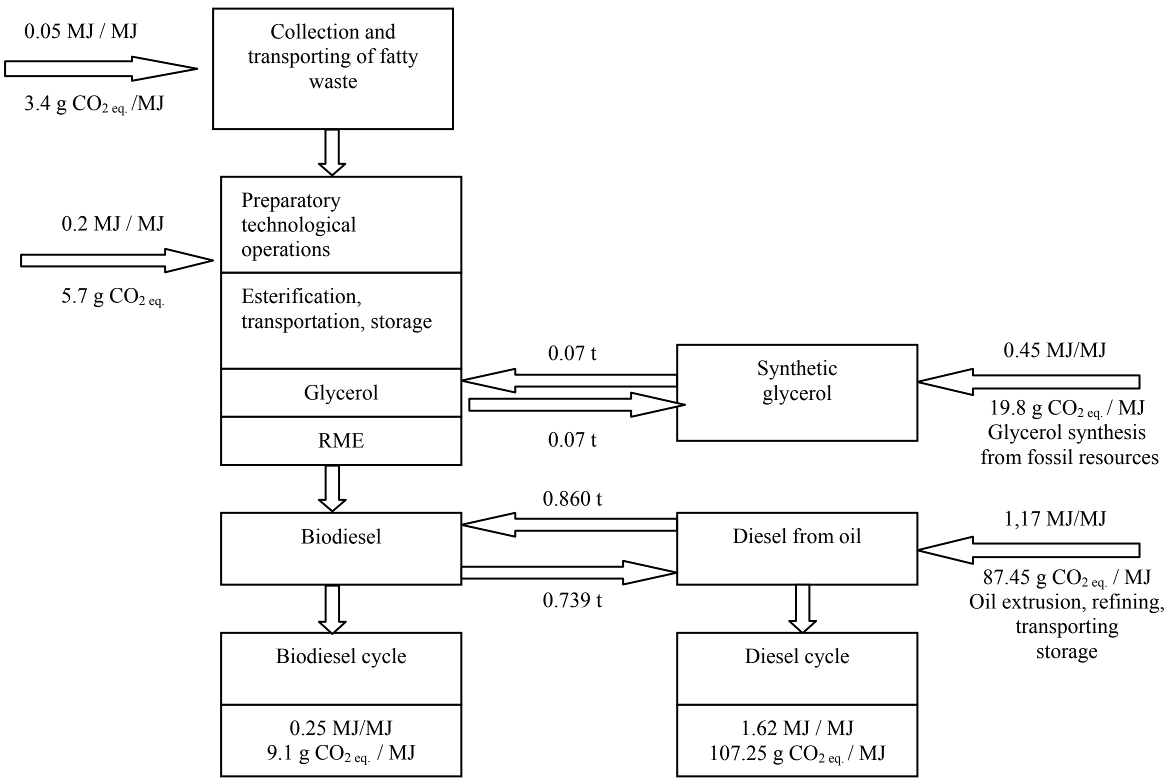


Fig. 4. Comparison of the life cycle of biodiesel from fatty waste and diesel before using them in engines

5. Evaluation of greenhouse gas emissions after fuel is burnt in an engine

Greenhouse gases are emitted during both the biofuel production and after it is burnt in engine. Since there is almost no sulphur and a little amount of carbon in used fats methyl ester (Table 3) and calorific value of fuel differs slightly from that of traditional diesel fuel (Table 5), it is possible to state that after biodiesel fuel has burnt less carbon dioxide as well as less other greenhouse gases will be emitted (Lapuerta 2008). Calculations done according to formula (1) have indicated that burning of 1 kg of diesel fuel in an engine emits3.16 kg of CO_2, into atmosphere while 1 kg of burnt rape methyl easter and used fats methyl ester – 2.83 kg CO_2.

Following the earlier analyses (Lapinskiene et al. 1999, Montrimaite et al. 2002) biofuel CO_2 forms almost a closed cycle (80%) therefore it has been taken into account in calculations.

In order to evaluate more in detail the environmental advantage in respect to climate change, the amount of greenhouse gases life cycle of diesel and biofuel from various raw materials has been calculated and comparatively analyzed (Table 5).

Table 5. Comparison of the amounts of greenhoude gases life cycles

Fuel type	Amount of greenhouse gases, g/MJ			Potential of greenhouse gases reduction
	Production phase	Burning in engines phase	Total amount of lifecycle gases	
Diesel	117. 6	73.83	191.43	-
RME	32.4	15.21	47.61	0.75
Used fats methyl ester	9.1	15.38	24.48	0.87

Having calculated the potential of greenhouse gas reduction it has been determined that the potential of used fats methyl ester greenhouse gas reduction during the life cycle is 0.87% and is 27% greater than that of methyl ester.

Using and producing biofuels the amount of CO_2 in the atmosphere is significantly reduced ant this is important from the point of global greenhouse gases control.

Used fats methyl ester meets the balancing criteria, nevertheless in our country waste collection system from food industry and catering enterprises is to be established.

6. Conclusions

1. Comparative analysis of the life cycle of biodiesel and diesel before using them in engines has indicated that in the production of rape methyl ester the growing of rape seeds consumes 56% of energy whose expenditure is directly dependent on rape productivity. In order to reduce energy expenditure it is expedient to seek an alternative feedstocks for biodiesel production.
2. Comparison of the life cycles of diesel and fatty waste methyl ester has allowed determine that production of biodiesel from used fats yields 1.37 MJ and 98.15 g $CO_{2eq.}$economy for one MJ of product. Comparing to rape methyl ester 0.45 MJ of energy and 23.3 g $CO_{2eq.}$ are economized for one MJ of product.
3. Calculations of the potential of greenhouse gas reduction have enabled us to determine that the potential of used fats methyl ester during their life cycle reaches 0.87 and is 27 % greater than that of rape methyl ester. Used fats methyl ester meets the balance criteria therefore in our country a collection system from food industry and catering enterprises is to be established.
4. To implement the EU Directives and achieve greenhouse gas emissions reduction in the use of fatty waste for biodiesel production is expedient.

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Šiltnamio dujų mažinimo potencialas, gaminant ir naudojant biodyzeliną iš riebalinių atliekų

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Klimato kaitos, ekonomikos ir energetinės atskirties problemų sprendimas susijęs su biodegalų naudojimo ir gamybos plėtra. Didinant biodyzelino naudojimą ir gamybą, būtina užtikrinti ir šiltnamio dujų išlakų mažėjimą.

Taikant būvio ciklo metodą, atlikta rapso metilo esterio ir dyzelino lyginamoji analizė iki panaudojimo dyzeliniuose varikliuose, kuri parodė, kad gaminant rapso metilo esterį rapsų sėkloms auginti sunaudojama (56 %) energijos, kurios sąnaudos tiesiogiai priklauso nuo rapsų derlingumo. Siekiant mažinti energijos sąnaudas, biodyzelino gamybai tikslinga ieškoti alternatyvių žaliavų. Nustatyta, kad gaminant biodyzeliną iš kepimui panaudotų riebalų gaunama 1,37 MJ ir 98,15 g CO_{2ekv} ekonomija 1 MJ pagamintos produkcijos, palyginti su dyzelinu. Panaudotų riebalų metilo esterio šiltnamio dujų redukcijos potencialas būvio cikle siekia 0,87 ir yra 27 % didesnis už rapso metilo esterio šiltnamio dujų redukcijos potencialą. Panaudotų riebalų metilo esteris atitinka subalansuotumo kriterijus, todėl mūsų šalyje būtina sukurti atliekų surinkimo sistemą iš maisto pramonės ir viešojo maitinimo įmonių.