UFU

Brazilian Geographical Journal: Geosciences and Humanities research medium

ARTICLES/ARTIGOS/ARTÍCULOS/ARTICLES

A brief discussion of general aspects of Biodiesel Production

Doctor Antonio Carlos Ferreira Batista
Prof. do Curso de Química, Laboratório de Energias Renováveis e Meio Ambiente do Pontal (LERMAP), Faculdade de Ciências Integradas do Pontal, *Campus* do Pontal, Universidade Federal de Uberlândia, Rua Vinte, 1600, Bairro Tupã, 38304-402 Ituiutaba, Minas Gerais, Brazil. **E-mail:** flash@pontal.ufu.br

Undergraduate student in Chemistry Tiago Almeida Silva
Bolsista de Iniciação Tecnológica do CNPQ na área de Biocombustíveis, Laboratório de Energias Renováveis e Meio Ambiente do Pontal (LERMAP), Faculdade de Ciências Integradas do Pontal, *Campus* do Pontal, Rua Vinte, 1600, Bairro Tupã, 38304-402 Ituiutaba, Minas Gerais, Brazil. **E-mail:** tiago_almeida@qui.pontal.ufu.br

Chemistry Andressa Tironi Vieira
Bolsista de DTI do CNPQ na área de Biocombustíveis, Laboratório de Energias Renováveis e Meio Ambiente do Pontal (LERMAP), Faculdade de Ciências Integradas do Pontal, *Campus* do Pontal, Rua Vinte, 1600, Bairro Tupã, 38304-402 Ituiutaba, Minas Gerais, Brazil. **E-mail:** dessaqtironi@yahoo.com.br

ARTICLE HISTORY

Received: 16 November 2011
Accepeted: 29 June 2012

KEY-WORDS:
Biodiesel
Biodiesel chemistry
Economy
Social inclusion
Environment

ABSTRACT

Environmental concerns dominate the world scene in the XXI century. The petroleum and its derivatives are a major contributor to the non-renewable sources of energy. However, there are forecasts that in a time near the main sources of petroleum may exhaust. Thus, the search for alternative sources of energy, beside environmental necessity is essential to ensure the well being of all. The mineral diesel, the main petroleum derivative, is an extremely fuel used. Its use in diesel engines leads to high rates of emission of greenhouse gases. A potential substitute for diesel fuel is biodiesel. Biodiesel consists of alkyl esters of long chain carboxylic acids, from renewable sources such as vegetable oils or animal fats. The introduction of biodiesel in the energy matrix has been stimulated by environmental factors, where studies have shown that the burning of biodiesel leads to significant reduction of greenhouse gases, and also economic and social factors.

PALAVRAS-CHAVE:
Biodiesel
Química do biodiesel
Economia
Inclusão social
Meio ambiente

RESUMO - UMA BREVE DISCUSSÃO DOS ASPECTOS GERAIS DA PRODUÇÃO DE BIODIESEL. As preocupações ambientais

dominam o cenário mundial no atual século XXI. O petróleo e seus derivados são um dos principais responsáveis pelas fontes não-renováveis de energia. No entanto, há previsões de que em um tempo próximo as principais fontes de petróleo poderão se esgotar. Sendo assim, a procura por fontes alternativas de energia, além de uma necessidade ambiental é indispensável para garantia do bem estar de todos. O diesel mineral, principal derivado do petróleo, é um combustível extremamente utilizado. Sua utilização em motores de ciclo Diesel leva a elevados índices de emissão de gases do efeito estufa. Um potencial substituto do diesel mineral é o biodiesel. O biodiesel é composto por ésteres alquílicos de ácidos carboxílicos de cadeia longa, provenientes de fontes renováveis como óleos vegetais ou gorduras animais. A inserção do biodiesel na matriz energética tem sido estimulada por fatores ambientais, onde estudos mostraram que a queima de biodiesel leva a diminuição significativa dos gases do efeito estufa, e também fatores econômicos e sociais.

PALABRAS-CLAVE:
El biodiesel
Química del Biodiesel
Economía
Inclusión Social
Medio ambiente

RESUMEN - UNA BREVE DISCUSIÓN DE LOS ASPECTOS GENERALES DE PRODUCCIÓN DE BIODIESEL. Preocupaciones ambientales dominan el escenario mundial en el siglo actual. El petróleo y sus derivados son un importante contribuyente a las fuentes no renovables de energía. Sin embargo, hay pronósticos de que en un tiempo cerca de las principales fuentes de petróleo pueden ser agotados. Por lo tanto, la búsqueda de fuentes alternativas de energía, y una necesidad del medio ambiente es esencial para asegurar el bienestar de todos. El gasóleo mineral, el derivado de aceite principal, es un combustible muy utilizado. Su uso en motores de ciclo diesel conduce a altas tasas de emisión de gases de efecto invernadero. Un posible sustituto para el gasóleo es el biodiesel. El biodiesel cuenta con ésteres de ácido carboxílico de cadena larga, a partir de recursos renovables como aceites vegetales o grasas animales. La inclusión de biodiesel en la energía se ha visto estimulado por factores ambientales, donde los estudios han demostrado que la combustión de biodiesel produce una reducción significativa de los gases de efecto invernadero, y también factores económicos y sociales.

1. Introduction

Over the past 50 years concerns about the problems of environmental protection has increased and dominated the world scene (SILVA; OLIVEIRA, 2011). A significant part of these concerns is associated with intensive use of non-renewable energy resources and the enormous pollution from the consumption of these resources. The petroleum and its derivatives have been extensively used for more than a century. The mineral diesel, the main petroleum derivative, is the source of energy that moves the transport and ensures the development world. The lack of diesel in the world today is unimaginable, and yet, there are forecasts that in the coming decades various sources of petroleum may go extinct (VYAS; VERMA; SUBRAHMANYAM, 2010).

Within this scenario a big boost has been given in order to develop technological systems capable of work under the use of renewable energy sources like solar, wind, biofuels, etc. (LA ROVERE; PEREIRA; SIMÕES, 2011; BAROUDI; DINAVAHI; KNIGHT, 2007; BAHNEMANN, 2004).

Although the use of biofuels in diesel engines have been thoroughly researched and promoted only after the 80's, the idea of using vegetable oils in internal ignition engines is much older than think (VYAS; VERMA; SUBRAHMANYAM, 2010). In fact, this possibility goes back the first operation of internal ignition engine. It was in

1898 that Rudolf Diesel, the diesel engine creator, launched at the Paris Fair your engine running with peanut oil, and with an efficiency superior to the classic steam engines known so far (RAMEZANI; ROWSHANZAMIR; EIKANI, 2010; RINALDI *et al.*, 2007).

Among biofuels, biodiesel stands out as the main diesel substituent. Biodiesel is a fuel derived from renewable sources like vegetable oils and animal fats and can be used whole or in part in diesel engines, without any need for upgrading of the engine (MORSHED *et al.*, 2011; LIANHUA *et al.*, 2010).

In this paper, we present a discussion of general aspects related to the production of biodiesel, such as the chemical aspects, economic, social and environmental.

To fulfill this objective, the methodology consisted in the study of specialized literature (such as articles, book chapters and specialized sites).

2. The Chemistry of Biodiesel

The use of vegetable oils as fuels in engines has as their main problem its high viscosity, coming to be 10-20 times higher than mineral diesel (VYAS; VERMA; SUBRAHMANYAM, 2010; DEMIRBAS, 2008). For this reason, to be used as fuel must undergo some chemical process to suit its use (VYAS; VERMA; SUBRAHMANYAM, 2010).

The process of reducing the viscosity of oils gives rise to biodiesel. Chemically, the American Society for Testing and Materials (ASTM) defines biodiesel as alkyl esters of long chain carboxylic acids, from renewable sources such as vegetable oils or animal fats derived from renewable agricultural lipids (ZHANG *et al.*, 2003).

The main technological routes of production of biodiesel from vegetable oils or animal fats are the transesterification, esterification and cracking (HELWANI *et al.*, 2009). Among these three the transesterification has been most often employed. Transesterification is the reaction of oil with a short chain alcohol (methanol or ethanol) in the presence of a catalyst. Industrially, the catalytic transesterification of vegetable oils with methanol is an important method used in the synthesis of biodiesel (SILVA *et al.*, 2006). Usually, industries use sodium methoxide or potassium as a catalyst, since they are relatively cheap and very actives for this reaction (VICENTE; MARTÍNEZ; ARACIL, 2004). An overview of the transesterification reaction is shown in figure 1.

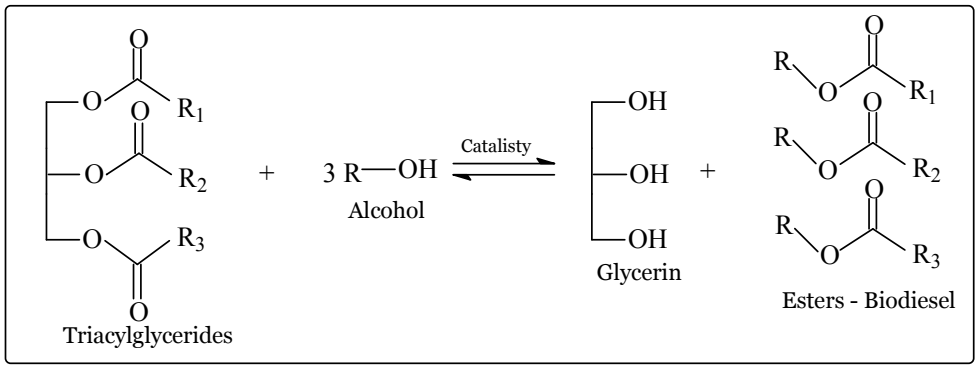

Figure 1. General equation for the transesterification reaction (organized from SILVA, BATISTA, 2010).

The use of biodiesel in diesel engines can be made fully or as blends with conventional diesel fuel. To refer to the percentage of biodiesel added to diesel created a nomenclature used worldwide, the BX, where X represents the percentage of biodiesel in the blend. For example, B10 means 10% of the mixture consists in biodiesel (SHANG *et al.*, 2010).

The oils that can be used to produce biodiesel are numerous. From this point the Brazil stands out for have an impressive diversity of potential sources to be used for this purpose. Several studies have been published by Brazilian researchers with different types of oils. Among the various possibilities can be mentioned castor (SOUSA; LUCENA; FERNANDES, 2010), soybeans (FERRARI; OLIVEIRA; SCABIO, 2005), sunflower (GAMA; GIL; LACHTER, 2010), etc.

In recent studies, our group has shown that pequi (BORGES *et al.*, 2012), baru (BATISTA *et al.*, 2012), peanuts (SILVA; BATISTA, 2010), tucum (OLIVEIRA *et al.*, 2011) and Jatropha (PORTELA *et al.*, 2011) produced biodiesel of physical and chemical characteristics satisfactory.

The efficient use of biodiesel is given by the attendance of a set of rules that determine their physical and chemical standards. In the United States is the standard of ASTM D6751, in European countries is the standard EN 14214 and in Brazil the National Agency of Petroleum, Natural Gas and Biofuels (ANP) is the organ responsible for setting the Brazilian standard of biodiesel quality and monitoring. The properties of biodiesel, which are determined by the component structure of fatty esters, include ignition quality, heat of combustion, cold flow, oxidative stability, viscosity and lubricity (SARIN *et al.*, 2009; KNOTHE, 2005).

3. Biodiesel and the social and economic issues

There are predictions that by 2050, half of the total energy consumed in developing countries will be supplied by energy from biomass. Intensive use of biomass in future energy supply will need of 385 million hectares of vegetables worldwide, and three quarters of this area will be located in developing countries (KARTHA; LARSON, 2000).

In today's world the biomass energy already represents a large share of all energy consumed by human activity, as evidenced by Figure 2.

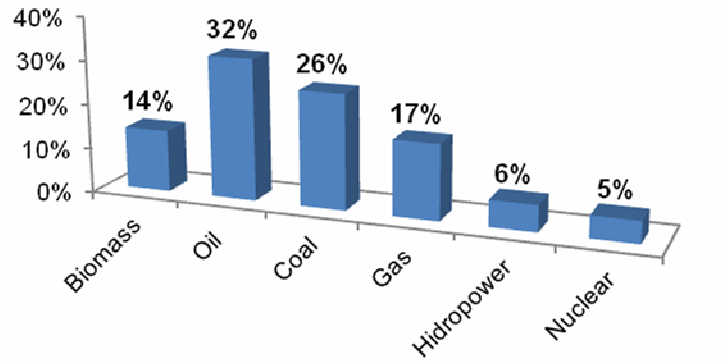

Figure 2. Sources of world energy (modified from HARPER; STARBUCK, 2009).

The use of biomass for bio-materials will increase, both in well established markets (such as construction, paper), and possibly large new markets (such as biochemical and plastics) as well as the use of charcoal for steel production (HOOGWIJK *et al.*, 2003).

With respect to fuels produced from biomass, biofuels, there are two strong candidates to replace gasoline and diesel fuel. These are bioethanol and biodiesel (HAHN-HAGERDAL *et al.*, 2006; KNOTHE, 2010). Transport is one of the sectors

that most energy consuming, and therefore the search for new fuels is necessary (LA ROVERE; PEREIRA; SIMÕES, 2011).

The production cost of biodiesel depends on a complex system of economy that begins with the infrastructure of agricultural production, processing of oil or other promising sources such as algae, which will be specific to the regions ideal for harvest. In addition, other costs that arise is the cost of a catalytic process used in the transesterification, analytical techniques to quality analyze and the remaining steps considered in the final economic cost including transportation of biomass to extraction, storage and distribution of biodiesel, etc. . However, the final cost of biodiesel depends largely on the region or country where it is produced, the costs involved in each type of raw material, etc. (DRAPCHO, NHUAN; WALKER, 2008).

The use of biofuels in many cases can only be possible through a public program to encourage the production of biofuels. Such program must have aid for the cultivation of raw materials and the capital cost of biofuel processing. In this topic, our country is well highlighted, with the National Program of Biodiesel Production and Use (Programa Nacional de Produção e Uso de Biodiesel - PNPB), which aims to implement of a sustainable way, both technically, and economically, the production and use of biodiesel, with a focus on social inclusion and regional development through employment generation and income (GARCEZ; VIANNA, 2009).

It is believed that the production of biodiesel may be an important means of stimulating economic growth in poor areas, by expanding the production of local oilseeds sources, which consequently leads to job creation and also the foreign exchange savings by reducing in petroleum imports (PARENTE, 2008).

Brazil has the advantage of being a huge country with tropical climate, so we have a wide variety of grain crops. Moreover, already has a considerable accumulation of research on raw material production, oilseed crushing and biodiesel production, developed by universities, research centers and private companies. It is also important to say that, apart from being a viable energy alternative and be a substitute for petroleum (whose use should be directed to the noblest uses, once the world's reserves will be depleted in the future), the strategic importance of the production of biodiesel for the country is the promotion of agricultural and industrial activities in the country, avoiding the expenditure of resources that are now spent to import the diesel (LA ROVERE; PEREIRA; SIMÕES, 2011; PINTO *et al.*, 2005).

Currently Europe is the region with the highest production of biodiesel, and is increasing, as shown in Figure 3. In North America, especially its largest producer, the USA, biodiesel production decreases from 2008, possibly due to changes in federal subsidies for biodiesel, due to the economic downturn. The Asia and Oceania have also realized the benefits of biodiesel and production in these regions has increased significantly, and presents a huge production potential. Also the Latin American region has great potential for biodiesel production, especially Brazil, accounting for nearly 50% of production in the region in 2010, figure 4 (EIA). Figure 5 clearly illustrates the distribution of world production of biodiesel in 2009, showing also the main oil sources used in each region/country (IZQUIERDO, 2009).

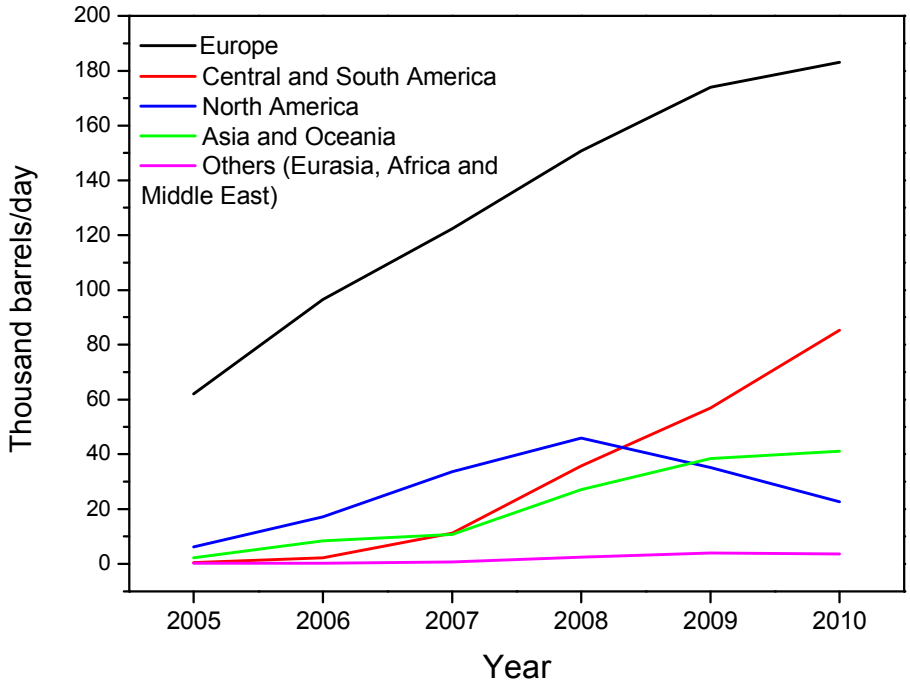

Figure 3. Biodiesel production by world regions between 2005 and 2010 (organized from EIA Biodiesel Production).

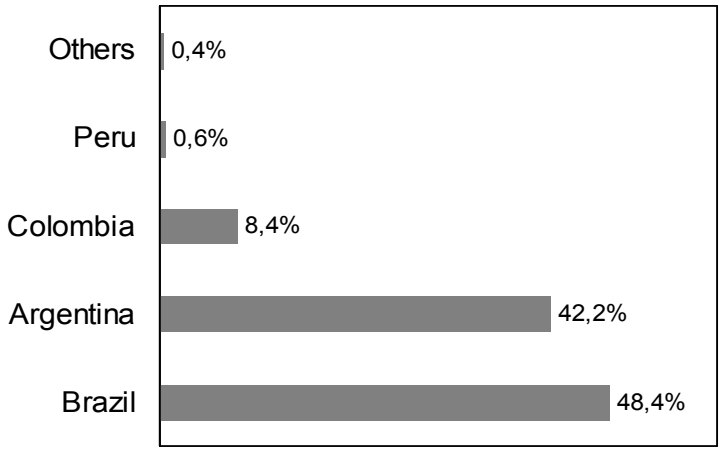

Figure 4. Biodiesel production of the South America in 2010 (organized from EIA Biodiesel Production).

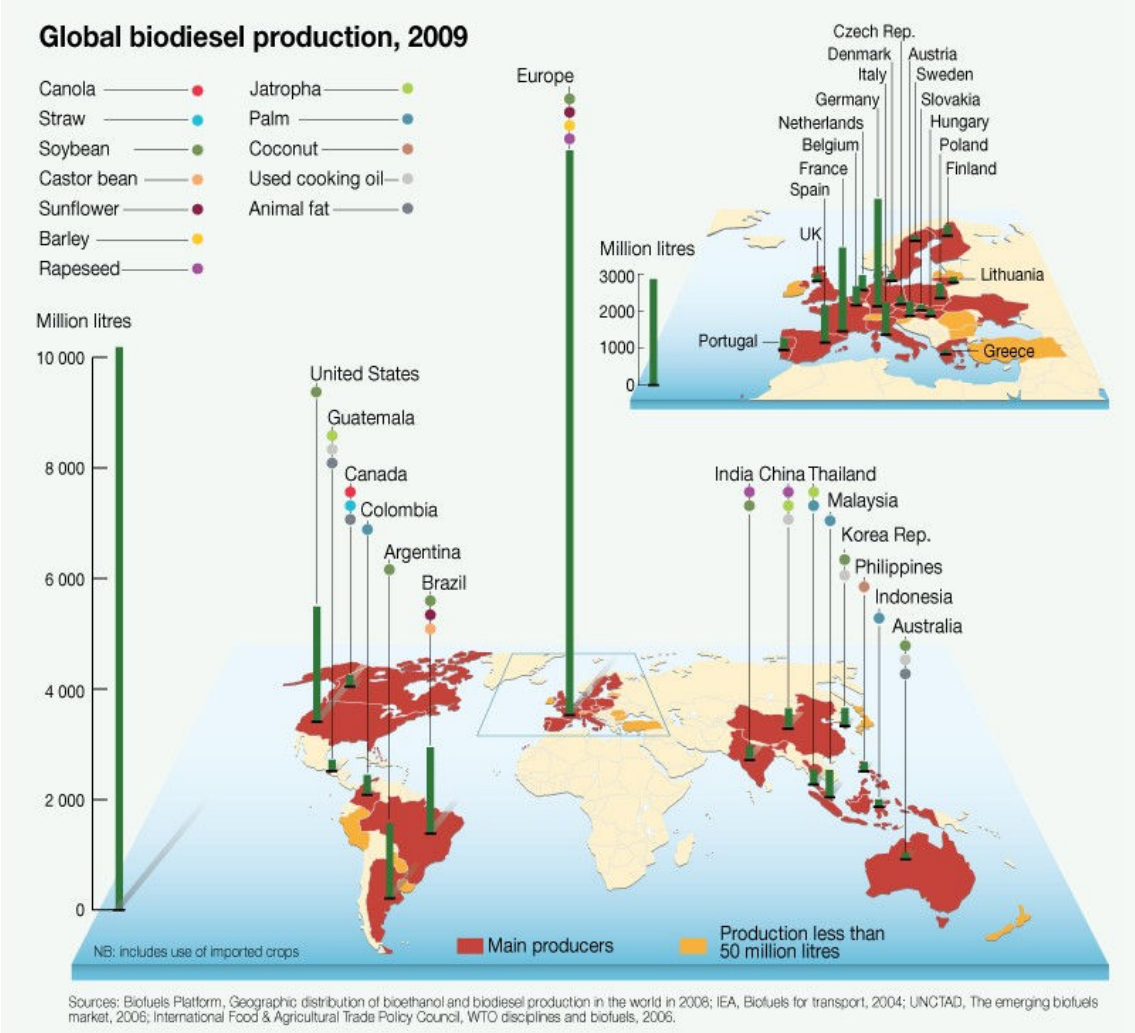

Figure 5. Global biodiesel production in 2009 (IZQUIERDO, 2009).

4. Biodiesel and environmental issues

Much of the current problems in the quality of the environment stems from the burning of fossil fuels derived from petroleum. Air pollution, climate change, petroleum spills and toxic waste generation are the result of the use and production of these fuels.

Air pollution from large cities is probably the most visible impact of the burning of petroleum. In the United States, the fuel consumed by cars and trucks are responsible for issuing 67% of carbon monoxide - CO, 41% of nitrogen oxides - NO_x, 51% of reactive organic gases, 23% of particulate matter and 5% of sulfur dioxide - SO_2. In addition, the transportation sector also accounts for almost 30% of emissions of carbon dioxide - CO_2, a major contributor to global warming (LIMA, 2004).

The effect of the higher concentration of CO_2 in the atmosphere is an aggravation of the original benefit of the greenhouse effect, that is, the planet tends to heat more than normal, and in other words, the Earth's average temperature is rising and may have serious consequences for humanity (OLIVEIRA; SILVA, 2011)

The use of biodiesel represents a significant environmental gain in terms of reducing emissions (LA ROVERE; PEREIRA; SIMÕES, 2011). This is because the biodiesel which allows to establish a closed carbon cycle in which CO_2 is absorbed when the plant grows and is released when biodiesel is burned in the combustion engine, according to figure 6 (OLIVEIRA; SUAREZ; SANTOS, 2008).

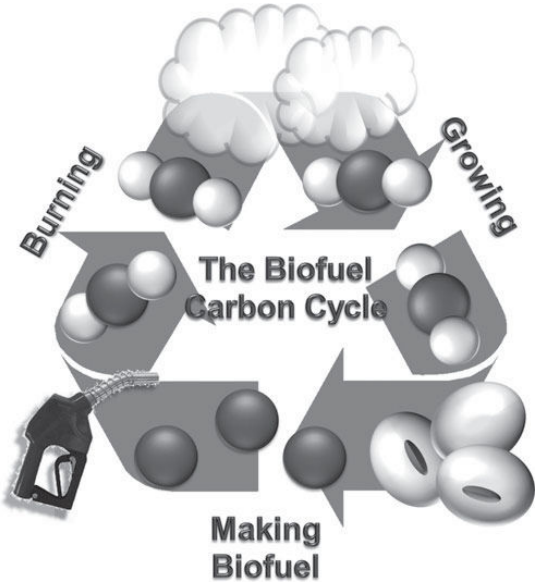

Figure 6. The biofuel carbon cycle (HARPER; STARBUCK, 2009).

A joint study of the Energy Department and the Department of Agriculture of the United States shows that biodiesel reduces 78% of CO_2 emissions. However, European Union study shows that NO_x emissions are worse than those of petroleum diesel (LIMA, 2004). Table 1 illustrates the environmental benefits in reducing greenhouse gases, according to some mixtures BX.

Table 1. Profile of emissions of pure biodiesel (B100) and some blends with mineral diesel (BERMANN, 2008).

Pollutant	B100 (%)	B20 (%)	B10 (%)	B5 (%)
Greenhouse gases	-78	-15	-7,5	-3,75
Sulfur oxides (SO_X)	-98	-19	-9,5	-4,95
Particulate matter	-50	-10	-5	-2,5
Nitrogen oxides (NO_X)	+13	+2,5	+1,3	+0,65

Environmental benefits can also generate economic benefits for the producer of biodiesel, by inserting biodiesel in the agreements of the Kyoto Protocol and the guidelines of the Clean Development Mechanism - CDM. Then there is the possibility of sell carbon quotas through the Prototype Carbon Fund - PCF, by reducing emissions of greenhouse gases and also carbon credits through the Bio Carbon Fund - CBF, administered by World Bank (LA ROVERE; PEREIRA; SIMÕES, 2011).

Countries like Japan, Spain, Italy and countries of the northern and Eastern Europe have shown interest in producing and importing biodiesel, especially by environmental motivation.

5. Final Considerations

Recently several attempts have been made to develop new renewable energy sources, since projected depletion of nonrenewable resources. In this context, there is also the concern about environmental problems related to emissions of greenhouse gases generated by burning fossil fuels derived from petroleum. An alternative to replacement of mineral diesel, the main petroleum derivative, is biodiesel.

The production of biodiesel, as well as having an environmental nature, through the reduction in emissions with the closed cycle of carbon, must also consider the economic and environmental benefits arising from production of biodiesel. Biodiesel production can increase production of plant sources in the poorest regions, leading to job creation and improving the local quality of life. In addition, the introduction of biodiesel in the energy matrix of many countries may lead the foreign exchange savings by the reduction in diesel imports.

Generally speaking, biodiesel is a biofuel whose study is quite consolidated, and its proven benefits. However, to it may take this character, and really contribute, both environmentally and in terms of social and economic issues, the production should be well planned, in order to adjust their production in each region.

Acknowledgments

The authors gratefully acknowledge the CNPq for an initiation technological scholarship and the funding of research projects of the Research Group Laboratório de Energias Renováveis e Meio Ambiente do Pontal.

References

BAHNEMANN, D. Photocatalytic water treatment: solar energy applications. **Solar Energy**, v. 77, n. 5, p. 445-459, 2004.

BAROUDI, J. A.; DINAVAHI, V.; KNIGHT, A. M. A review of power converter topologies for wind generators. **Renewable Energy**, v. 32, n. 14, p. 2369-2385, 2007.

BATISTA, A. C. F. et al. Use of baru oil (Dipteryx alata Vog.) to produce biodiesel and study of the physical and chemical characteristics of biodiesel/petroleum diesel fuel blends. **Chemistry and Technology of Fuels and Oils**, v. 48, n. 1, p. 13-16, 2012.

BORGES, A. K. et al. Production of methylic and ethylic biodiesel from pequi oil (*Cariocar Brasiliensis Camb*). **Chemistry and Technology of Fuels and Oils**, v. 48, n. 2, p. 83-89, 2012.

BERMANN, C. Crise ambiental e as energias renováveis. **Ciência e Cultura**, v. 60, n. 3, p. 20-29, 2008. DEMIRBAS, A. Biodiesel production via rapid transesterification. **Energy Sources Part A**, v. 30, n. 7, p.1830-1834, 2008.

DRAPCHO, C. M.; NHUAN, N. P.; WALKER, T. H. **Biofuels Engineering Process Technology**. 1. ed., New York: McGraw-Hill, 2008, p. 250.

FERRARI, R. A.; OLIVEIRA, V. S.; SCABIO, A. Biodiesel de soja – taxa de conversão em ésteres etílicos, caracterização físico-química e consumo em gerador de energia. **Química Nova**, v. 28, n. 1, p. 19-23, 2005.

GAMA, P. E.; GIL, R. A. S. S.; LACHTER, E. R. Produção de biodiesel através de transesterificação *in situ* de sementes de girassol via catálise homogênea e heterogênea. **Química Nova**, v. 33, n. 9, p. 1859-1862, 2010.

GARCEZ, C. A. G.; VIANNA, J. N. S. Brazilian Biodiesel Policy: Social and environmental considerations of sustainability. **Energy**, v. 34, n. 5, p. 645-654, 2009.

HAHN-HAGERDAL, B. et al. Bio-ethanol: the fuel of tomorrow from the residues of today. **Trends in Biotechnology**, v. 24, n. 12, p. 549-556, 2006.

HARPER, G. D. J.; STARBUCK, J. **Run Your Diesel Vehicle on Biofuels**. 1 ed., New York: McGraw-Hill, 2009, p.12.

HELWANI, Z. et al. Technologies for production of biodiesel focusing on green catalytic techniques: A review. **Fuel Processing Technology**, v. 90, n. 12, p. 1502-1514, 2009.

HOOGWIJK, M. et al. Exploration of the ranges of the global potential of biomass for energy. **Biomass and Bioenergy**, v. 25, n. 2, p. 119-133, 2003.

IZQUIERDO, N. L. Global production biodiesel in 2009. Biofuels Vital Graphics – Powering Green Economy, UNEP/GRID-Arendal, 2012. Available at: < http://www.grida.no/graphicslib/detail/global-biodiesel-production-2009_4e7c#>. Access: 06 may 2012.

KARTHA, S.; LARSON, E. D. **Bioenergy primer: Modernized biomass energy for sustainable Development**. 1 ed., New York: United Nations Publications, 2000, p. 14.

KNOTHE, G. Biodiesel and renewable diesel: A comparison. **Progress in Energy and Combustion Science**, v. 36, n. 3, p. 364-373, 2010.

KNOTHE, G. Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. **Fuel Processing Technology**, v. 86, n. 10, p. 1059-1070, 2005.

LA ROVERE, E. L.; PEREIRA, A. S.; SIMÕES, A. F. Biofuels and Sustainable Energy Development in Brazil. **World Development**, v. 39, n. 6, p. 1026-1036, 2011.

LIANHUA, L. et al. Esterification of high FFA tung oil with solid acid catalyst in fixed bed reactor. **Biomass and Bioenergy**, v. 34, n. 4, p. 496-499, 2010.

LIMA, P. C. R. O Biodiesel e a Inclusão Social - Consultoria Legislativa. Brasília, 2004. Available at:<http://apache.camara.gov.br/portal/arquivos/Camara/internet/publicacoes/estnottec/pdf/2004_676_Estudo.pdf>. Access in: 15 oct. 2011.

MORSHED, M. et al. Rubber seed oil as a potential source for biodiesel production in Bangladesh. **Fuel**, v. 90, n. 10, p. 2981-2986, 2011.

OLIVEIRA, F. C. C.; SUAREZ, P. A. Z; SANTOS, W.L.P. Biodiesel: Possibilidades e Desafios. **Química Nova na Escola**, v. 28, p.3-8, 2008.

OLIVEIRA, K. M.; SILVA, T. A. Efeito Estufa: causas e impactos ambientais. In: ENCONTRO DE GEOGRAFIA DO PONTAL - A GEOGRAFIA E AS QUESTÕES EMANCIPATÓRIAS NO SÉCULO XXI, 3., 2011, Ituiutaba. **Anais do III Encontro de Geografia do Pontal - A Geografia e as questões emancipatórias no século XXI**. Ituiutaba: Universidade Federal de Uberlândia, 2011, p. 16-16.

OLIVEIRA, M. F. O. et al. A Simple and Fast Method for the Production and characterization of Methylic and Ethylic Biodiesels from Tucum Oil via an Alkaline Route. **Journal of Biomedicine and Biotechnology**, v. 2011, p. 1-4, 2011.

PARENTE, E. J. S. **Biodiesel: Uma Aventura Tecnológica num País Engraçado**. 1 ed., Fortaleza: Grupo Santana e Gráfica da Câmara Federal, 2008, p. 54.

PINTO, A. C. et al. Biodiesel: An Overview. **Journal of the Brazilian Chemical Society**, v. 16, n. 6B, p. 1313-1330, 2005.

PORTELA, F. M. et al. Assessing the potential of producing methylic biodiesel from Jatropha Oil. **Journal of Biofuels**, v. 2, n.2, p. 1-11, 2011.

RAMEZANI, K.; ROWSHANZAMIR, S.; EIKANI, M. H. Castor oil transesterification reaction: A kinetic study and optimization of parameters. **Energy**, v. 35, n. 10, p. 4142-4148, 2010.

RINALDI, R. et al. Síntese de biodiesel: uma proposta contextualizada de experimento para laboratório de química geral. **Química Nova**, v. 30, n. 5, p. 1374-1380, 2007.

SARIN, A. et al. Effect of blends of Palm-Jatropha-Pongamia biodiesels on cloud point and pour point. **Energy**, v. 34, n. 11, p. 2016-2021, 2009.

SHANG, Q. et al. Properties of Tung oil biodiesel and its blends with 0# diesel. **Bioresource Technology**, v. 101, n. 2, p. 826-828, 2010.

SILVA, N. L. et al. Optimization of Biodiesel Production From Castor Oil. **Applied Biochemistry and Biotechnology**, v. 130, n. 1, p. 405-414, 2006.

SILVA, T. A.; BATISTA, A. C. F. Produção de biodiesel etílico e metílico á partir de óleo de amendoim empregando-se a reação de transesterificação via catálise homogênea básica. In: Encontro Luso-Galego de Química, 16., 2010, Aveiro**. Livro de Resumos do XVI Encontro Luso-Galego de Química**. Aveiro: Sociedade Portuguesa de Química & Universidade de Aveiro, 2010, p. 234-234.

SILVA, T. A.; OLIVEIRA, K. M. Descarte de óleos lubrificantes e suas embalagens: estudo de caso dos postos de gasolina e oficinas da cidade de Ituiutaba, Estado de Minas Gerais. **Observatorium**, v. 3, n. 7, p. 101-114, 2011.

SOUSA L. L.; LUCENA, I. L.; FERNANDES, F. A. N. Transesterification of castor oil: effect of the acid value and neutralization of the oil with glycerol. **Fuel Processing Technology**, v. 91, n. 2, p. 194-196, 2010.

U.S. Energy Information Administration, International Energy Statistics-Biodiesel Production. 2012. Available at: <http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=79&pid=81&aid=1&cid=regions&syid=2006&eyid=2010&unit=TBPD>. Access: 06 may 2012.

VICENTE, G.; MARTÍNEZ, M.; ARACIL, J. Integrated biodiesel production: a comparison of different homogeneous catalysts systems. **Bioresource Technology**, v. 92, n. 3, p. 297-305, 2004.

VYAS, A. P.; VERMA, J. L.; SUBRAHMANYAM, N. A review on FAME production processes. **Fuel**, v. 89, n. 1, p. 1-9, 2010.

ZHANG, Y. et al. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. **Bioresource Technology**, v. 89, n. 1, p. 1-16, 2003.