Chapter 16
Techno-Economic and Life Cycle Analysis of Biodiesel Production: Perception of Land Use, Climate Change, and Sustainability Measurements

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Abstract Motivation of this study is the strategic importance of bioenergy and biofuels for sustainable development of the global economy. Brazilian Bioenergy Program has enabled the consolidation of Brazil within the leading countries in the production of energy and renewable fuels. Within this program, biodiesel occupies a prominent position, influenced by significant technological, economic, environmental, and social advantages. This chapter covers issues like the life cycle analysis for the biodiesel production, allowing the mapping of resources, impacts of this economic activity, and the premises of sustainability. It also provides market information by analyzing the demand—production relationship, prices, and product quality supervision. Finally, it presents technical and economic parameters of the main technological routes of biodiesel production in Brazil (hydroesterification and transesterification) using current data and allowing the growing demand for new approaches and technological advances.

16.1 The Biodiesel Market

The next decade biofuel demand is increasing in Europe. However, non-European countries must represent more than 60 % of the world demand by 2030 and about 70 % by 2050. China, India, and Latin America will probably be the leaders in this market (Fig. 16.1).

Brazil holds an important position in the biofuel world scenario. Biodiesel has the advantage to be used pure or with diesel blends in internal combustion compression engines. In addition to the advantages of being produced locally, biodiesel has several environmental advantages compared to regular fossil diésel. Moreover,

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S. S. da Silva and A. K. Chandel (eds.), *Biofuels in Brazil*,
DOI: 10.1007/978-3-319-05020-1_16,

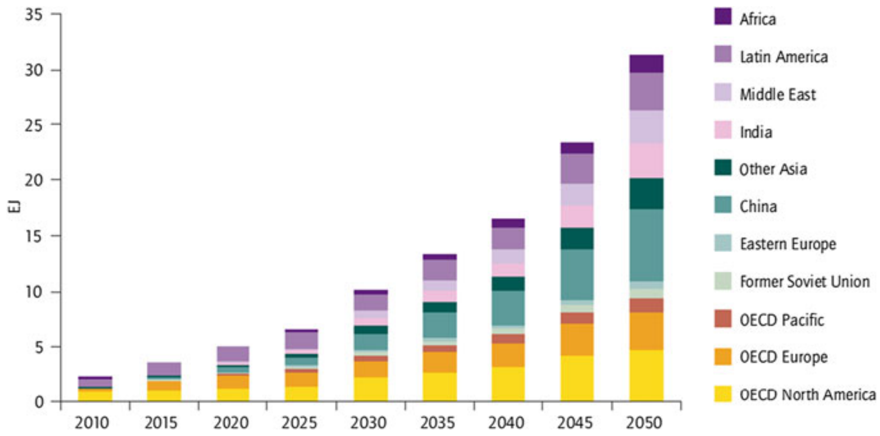

Fig. 16.1 Biofuel demand by region, 2010–2050 (IEA 2010)

social benefits and regional development with significant amount of new jobs and income can be obtained once its production and consumption are promoted in a non-centralized way with multiple feedstock (Ferreira and Oliveira 2010).

There are many factors that contribute to the increase in investments in biodiesel in Brazil. It is possible to mention the environmental pressures, world political instabilities, and uncertainty about the future of oil exploration, the social stimulus to agriculture, and the dependence on foreign diesel oil, where about 18 % of this fuel comes from.

Diesel oil is the principal fuel used in Brazil, because of the extensive use of road logistics all over the country that has been estimated by the Federal Government since the decade of the 1950s (Fig. 16.2).

Provisional Bill n° 214, from 13 September 2004, the Petroleum National Agency Agência Nacional do Petróleo (ANP) defines technically biodiesel as a fuel for combustion engines with internal compression ignition, renewable and biodegradable, derived from vegetable oils or animal fats which can replace partially or totally fossil diesel (Soares 2008).

In the Brazilian Biodiesel Standard, B100 is defined as a fuel consisting of alkyl esters of long chain fatty acids, derived from vegetable oils or animal fats. The B2 is a commercial fuel composed of 98 % by volume of diesel fuel, as ANP specification, and 2 % of biodiesel. The other compositions follow the models of B2 and B100 (Soares 2008).

The Brazilian law 11,097 of 2005 provides for the introduction of biodiesel into the Brazilian energy matrix, and sets to 5 % in volume its mandatory minimum starting at 2013.

However, since 1 January 2010, diesel fuel sold in Brazil contains 5 % biodiesel. This rule was established by Resolution No. 6/2009 of the National Energy Policy (CNPE), which increased from 4 to 5 % the mandatory percentage blending of biodiesel to diesel oil. The continued rise in the percentage of biodiesel added to

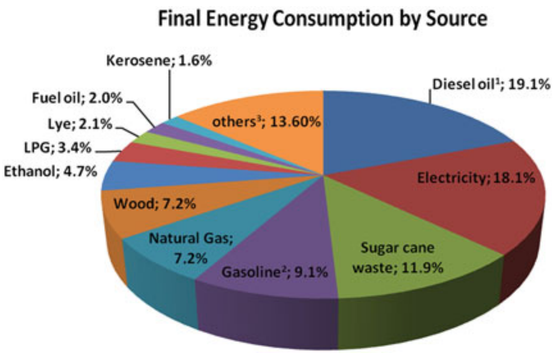

Fig. 16.2 Final energy consumption by source in Brazil, 2011 (Balanço Energético Nacional 2012)

diesel demonstrates the success of the National Program for Production and Use of Biodiesel and the experience accumulated by Brazil in the production and use of biofuels on a large scale (ANP 2013).

It is possible to highlight three groups that have been involved in biofuel production: those who already have the necessary resources (including agribusiness entrepreneurs, oil companies, plant operators, and small farmers); suppliers of products and services (including seed companies, engineering and equipment, and biotechnology), and the market participants (such as farmers, agricultural equipment companies, fertilizer suppliers, and logistics providers) (Caesar 2007 in Soares 2008).

In 2011, the amount of B100 produced in Brazil reached 2,672,760 m^3, against 2,386,399 m^3 in the previous year. Thus, there was an increase of 12 % in biodiesel available in the national market. In 2011, the percentage of B100 compulsorily added to mineral diesel remained constant at 5 %. The main raw material was soybean oil (81.2 %) followed by tallow (13.1 %) (Balanço Energético Nacional 2012).

Since 2005, the Petroleum National Agency performs biodiesel auctions where refineries buy biodiesel to be blended with fossil diesel. The initial purpose of the auction was to generate a permanent market and thereby stimulate the production of biodiesel to meet the national law (ANP 2013).

These auctions were structured for the period between 2005 and 2007, but to preserve the participation of family agriculture in the supply of raw materials, the government preferred to keep the systematic purchase through auctions after that period, rather than direct negotiations between producers and distributors or refineries, as occurs in the ethanol market (Amaral Mendes and Da Costa 2009).

The evolution of the biodiesel auctions can be evidenced in Fig. 16.3, from the first auction, which started with 70,000 m^3 in November 2005, until the thirtieth auction in April 2013 that fetched 488,532 m^3 (auction for 2 months delivery).

Figures 16.4, 16.5, and 16.6 summarize average prices in each biodiesel auction as organized by ANP. After several changes in the auction manner, currently, it involves a direct offering between biodiesel producers and fuel distribution companies.

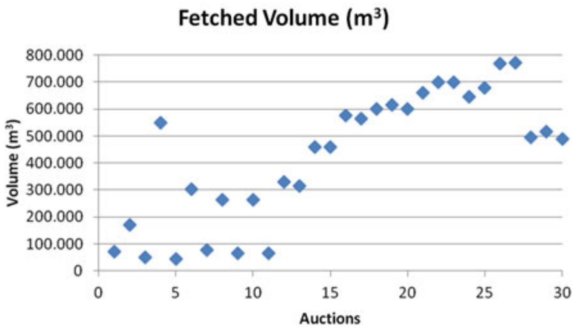

Fig. 16.3 Biodiesel auctioned volume—ANP auctions (ANP 2013)

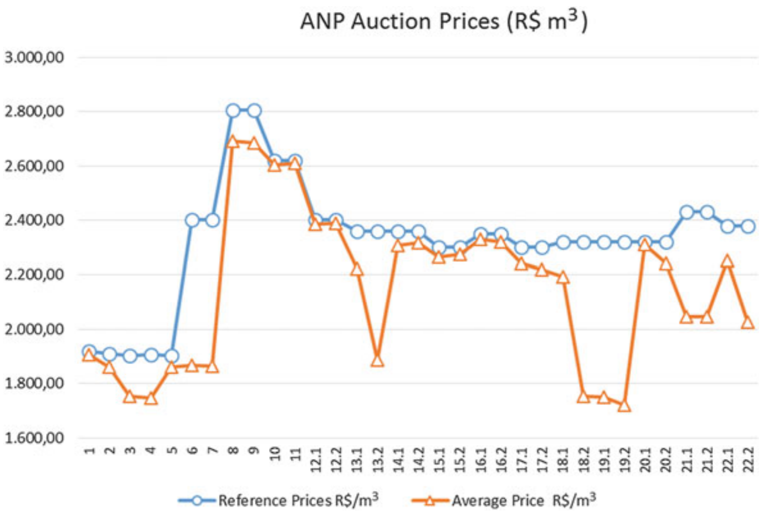

Fig. 16.4 Auction average prices 1–22 (ANP)

Despite being a new industry, the potential biodiesel offer is much higher than the mandatory demand. This means a dangerous industrial idling (Fig. 16.6). Until January, 2013, 64 biodiesel plants obtained operating licenses with a total capacity of 20,207.76 m^3/day. In the next few years, more plants are scheduled to work in addition to some extended size ones.

Biodiesel Program promotes social inclusion through deals involving biodiesel producers and small farmers. Agriculture Development Ministry published the "Instrução Normativa n° 1 de 20/06/2011," which currently regulates the "Social Fuel Seal." Basically, the biodiesel industries with purchase contracts with small farmers are included in the "Programa Nacional de Fortalecimento da Agricultura Familiar (Pronaf)." Once the producers have obtained this seal, they are able to obtain some tax reductions and special fundings. Producers have to purchase at least

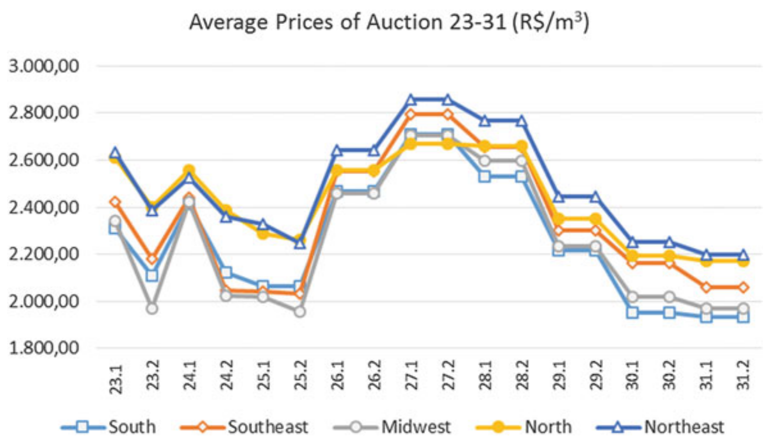

Fig. 16.5 Average prices in biodiesel auctions (ANP auction 23–31)

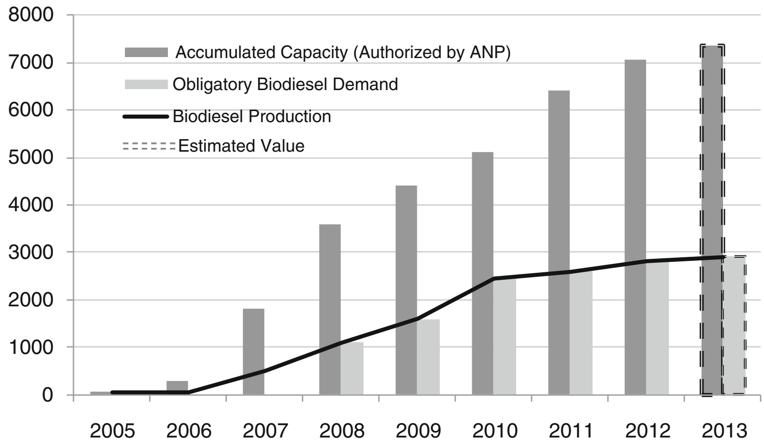

Fig. 16.6 Mandatory demand and operating licensed capacity for biodiesel plants in Brazil, 1000 m^3 (ANP 2013)

30 % of their feedstocks from Northeast, Southeast, and South region small farmers, or 15 % in the case of North or West-Central region (BRASIL/MDA 2011).

A part of biodiesel producers are asking for an open market phase instead of the regulated auctions as is currently done. In this case, ANP activity would be restricted to quality control as well as the blended biodiesel-diesel regulation.

Biodiesel development occurs in Brazil due to the mandatory process once its price becomes historically higher than mineral diesel. Average Price for B5 in April/2013 was R$2.33/L, 14 % higher than April/2012. This higher price is basically due to the higher prices of mineral diesel and not due to a more expensive biodiesel (Fig. 16.7).

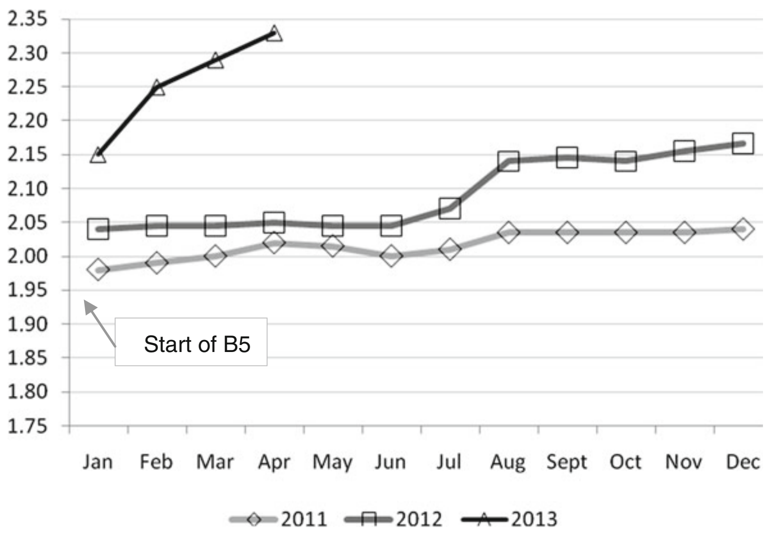

Fig. 16.7 B5 prices (R$/liter) (ANP 2013)

Table 16.1 Brazilian prices for biodiesel and mineral diesel (R$/m^3)

Fuel prices (R$/m^3)	2012	2013*	Δ %
Biodiesel—Auctions—ANP	2,187.91	2,249.42	2.8
Diesel in refinery	1,372.13	1,538.28	12.1
Diesel to distribution companies	1,816.50	2,002.75	10.3
Diesel in fuel station	2,041.25	2,259.50	10.7
Imported diesel	1,448.32	1,604.67	10.8

Source ANP (2013). Dólar/Brazilian Real Exchange, R$2.00/US$1.00
* 1st quarter of 2013

Average prices for biodiesel purchased in the auctions were between R$2,553.46/m^3 and R$2,213.57/m^3 in the first quarter of 2013 (Table 16.1). After that the price dropped to R$1,981.22/m^3. Comparing with the same period in 2012, prices were 2.8 % higher. At the same time, mineral diesel prices increased twice (ABIOVE 2013a, b).

It is important to stress that biodiesel price is ascribed to vegetable oil prices. Actually, biodiesel production cost is about 85 % of vegetable oil. In the Brazilian case, soybean oil price is relevant. It represents 75 % of the feedstocks to biodiesel. Another important factor in the biodiesel historical prices is the large amount of companies offering biodiesel in the auctions. In the ANP auctions, only the maximum prices are fixed; final prices are based on the competitive edge (Amaral Mendes and Da Costa 2010).

16.2 The Environmental Issue on Biodiesel

Once there is oxygen in its structure, biodiesel is able to promote a more complete combustion, reducing emissions of carbon monoxide (CO) and particulate matter, and increasing lubricity, guaranteed by sulfur in diesel, hence improving the life of engine components. There are also reductions in emissions of sulfur oxides because biodiesel does not contain sulfur. Furthermore, biodiesel provides a small increase in emissions of NOx for more than 20 % B20+ (Soares 2008). However, urea solution additive significantly reduces problems ascribed to NOx emissions in diesel engines.

The impact of NOx emissions by replacing diesel with biodiesel is not significant, but the reductions in CO, hydrocarbons, particulate matter, and poly-aromatics imply significant benefits (Monteiro 2005 in Soares 2008).

In general, it is considered that biodiesel is able to reduce the total greenhouse gases (GHG) emissions compared to diesel fuel. However, for a more comprehensive study of emissions from biofuels, it is necessary to consider some variables for the production of biodiesel, such as the production technology route, oilseed, and alcohol used in the process (Soares 2008).

16.3 Life Cycle Analysis of Biodiesel: An Overview of the Brazilian Case

Life Cycle Assessment (LCA) of a product or process is a management technique to quantify the mass flow, energy, and emissions assessing the environmental aspects and potential impacts from its production chain (Soares 2008).

ISO 14040, in the same group of ISO 14000, which establishes guidelines for corporate environmental management, indicates a methodology to life cycle assessment of products and services.

In order to estimate the environmental impact of the production and use of biodiesel, it is proposed a simplified life cycle analysis of its production.

The scope of this life cycle assessment includes two basic steps:

- an initial mapping of the most used vegetable oils in Brazil and potentially usable main raw materials for the biodiesel production;
- a mapping of biodiesel production key data in Brazil.

Another important issue is the land use. Most countries have a conflict between the land used for food plantations and the land dedicated to bioenergetic crops. In the case of Brazil, there are about 850 million ha including forests, cattle pasture, lakes, cities, etc. If one takes into account just the available land for new crops, the official number is about 90 million ha. One million hectares with palm plantation could produce about 5 million mton/year of palm biodiesel. This would mean a

Table 16.2 Biodiesel production by feedstock (m^3 biodiesel)

Feedstock	2008	2009	2010	2011	2012	2013
Soybean oil	801,320	1,250,577	1,960,822	2,152,298	2,042,730	466,588
Beef tallow	206,966	258,035	327,074	357,664	469,215	141,260
Cottonseed oil	18,353	59,631	57,458	84,711	123,325	26,797
Others	140,489	40,206	41,086	78,088	83,683	37,215
Total	*1,167,128*	*1,608,448*	*2,386,438*	*2,672,760*	*2,718,954*	*671,859*

Source/Preparation ANP (2013), ABIOVE 2013a, b—Coordination of economics and statistics

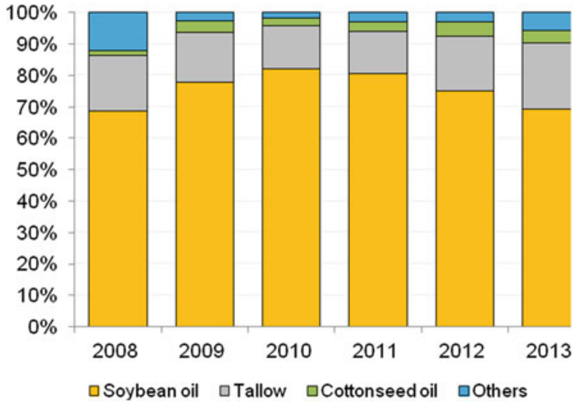

Fig. 16.8 Oilseeds market share for biodiesel production (ANP 2013; ABIOVE 2013a, b)

B10 program just with 1/90 of the available land. Thus, land use in Brazil is not a big issue. On the other hand, most of the Brazilian soybean producers are part of the Round Table on Responsible Soy Association (RTRS), which tracks the soybean origin. Soybean produced in a deforested area or using slavery labor conditions is not allowed.

16.3.1 The Oilseed Producing Biodiesel in Brazil

ABIOVE (Brazilian Association of Vegetable Oil Industries) considers that the biodiesel market is represented by the following oilseeds (Table 16.2).

These data contribute to the formation of the following market share of oilseeds for biodiesel production (Fig. 16.8).

It may be noted that soybean oil, beef tallow, and cottonseed oil contribute, on average, by about 90 % market share for feedstocks producing biodiesel.

It should also be noted that soybean oil is the main feedstock responsible for the production of fuel, representing more than 60 % of the total oilseed. The explanation for this lies in the fact that soybeans have a role as one of the main items of Brazilian agricultural production, due to its development observed more sharply since the 1970s, which enabled the crop to meet the biodiesel national market in an easy way. Brazil holds the second position in the world ranking for soybean production, behind only to USA.

Based on the soybean oil produced in Mato Grosso state, the farthermost soybean production center from the main consumption biodiesel places (São Paulo, Santos port, Paulínia fuel bases) Delta CO_2 company made an LCA of the pure soybean biodiesel (Delta CO_2 2013). Results indicated a reduction in the greenhouse gases to about 70 % compared to fossil diesel. If one considers the total amount of biodiesel being produced and consumed so far in Brazil, it means about 21 million m ton of avoided CO_2 due to the Brazilian biodiesel experience. It is important to emphasize that animal fat, the second more used feedstock, was not considered in this evaluation. Usually, animal fat biodiesel has an even better environmental performance than soybean.

Beef tallow is the second most widely used feedstock for biodiesel production and has contributed to almost 500,000 m^3 of fuel in 2012. This feedstock is also justified for the production of biodiesel because livestock is one of the main economic activities in Brazil. Brazil has the second largest herd in the world, behind India, currently occupying an area of almost 200 million ha—which is about three-fourths of the occupied area by the entire agricultural industry in the country.

Cottonseed oil contributed in recent years by 2–5 % of oilseeds for biodiesel production in Brazil. Cotton production in the country in 2011/2012 was over 1.8 million tons. Brazil is the fifth largest producer, behind China, India, Pakistan, and the United States, and is the third largest exporter of this oilseed (Abrapa 2013).

Among the other possible oilseeds that produce biodiesel, those that stand out as market reality are palm oil, babassu oil, castor bean oil, and sunflower oil. However, it is expected that the feedstocks used for this fuel would be diversified with advances in research and development in the Brazilian agricultural sector in order to reduce competition with food and land use, and optimize production and implementation costs, providing integration with the use of manpower to the agricultural industry in a socially dignified way.

The main trend for the future of biodiesel production in the country is the use of algae because of a significantly higher biomass productivity at current oil, which reduces the demand for extensive lands, besides the fact that they have carbon dioxide and light as their main inputs.

16.3.2 Biodiesel Production in Brazil

In general, the biodiesel market in the country still lacks important studies and research, such as life cycle assessment for the production and use of fuel associated with the market reality. This was observed through a simplified market research performed with some of the leading producers of biodiesel in Brazil.

These data reflect the difficulty to relate the relevant and reliable data on the life cycle assessment for the production of biodiesel in Brazil. Companies such as Petrobras, which conducts similar ongoing studies reflects a trend of concern about the alignment of fuel data to the company's need. There is also a series of academic studies focused on life cycle assessment of biodiesel, but each with its specific limitations and considerations that do not necessarily refer to a reality in the market.

The factors to be considered and inventoried for a life cycle assessment of the production and use of biodiesel reflecting the reality of Brazil are:

- Origin and indicators of production processes for the oilseeds employed;
- Distance, type of transport, and logistics, possible loss estimates associated with the origin of oilseed and its production process;
- Indicators of the production process for biodiesel;
- Distance, type of transport, and logistics possible losses estimate associated with the oilseed to the biodiesel production process;
- Origin and production process indicators of feedstock, supplies, and utilities for the biodiesel production processes;
- Distance, type of transport, and logistics possible loss estimates associated with the feedstocks, supplies, and utilities to the biodiesel production; and
- Indicators of the biodiesel use to the end consumer.

The indicators of the production of biodiesel should also consider the wastewater generation, solid waste, and gaseous emissions of its productive chain.

Amaral Mendes and Da Costa (2009) define the biodiesel industry as structured by companies with three distinct classifications in relation to its main feedstock: integrated, partially integrated, and nonintegrated.

The integrated companies have the cultivation or marketing of oilseeds step in its supply chain. These companies typically have greater competitiveness in the market due to greater flexibility of marketing products in accordance with the stages of its production.

The partially integrated company has the ability to produce, in addition to biodiesel, vegetable oil, although they do not sell or plant the crop plants.

The nonintegrated companies produce only biodiesel and are vulnerable to the oilseed price market fluctuations.

In relation to feedstocks, it is observed that besides oilseeds, the market mainly uses methanol as the reagent alcohol for the transesterification of the oil, despite the large supply of ethanol in the country. This is also explained by the large use of ethanol as an automotive fuel, as well as sugar and ethanol feedstock, an important item in the food market.

The use of ethanol as a feedstock potentially emits less greenhouse gases, since its production is made from sugarcane, which is renewable and widely exploited in various regions of the country. Methanol, in turn, has its origin in the petrochemical industry and is produced domestically only in the city of Rio de Janeiro, which is a negative fact for the logistics of the reagent to the producers.

The main supply input for biodiesel production is sodium methylate, which is used as a catalyst in the process.

The necessary utilities in this production are basically electricity and steam.

The National Program for Production and Use of Biodiesel was the major regulatory milestone for the compulsory and progressive use of the fuel in the country. However, as already mentioned, it was established by Law 11,097 in 2005, i.e., the growth of this market is still very recent. Therefore, it is still expected to be built a learning curve for the use of biodiesel in order to exploit natural resources in a better way to meet the same standards.

The Brazilian biodiesel market is fragmented. There are several producers with none having a market share larger than 16 %. Petrobras is the largest buyer but Shell, Exxon Mobil, Repsol, and Ipiranga are also important players. An important alternative to Brazilian producers could be export. However, the big international markets, like the European one, have technical restrictions to a pure soybean biodiesel. The main advantages of biodiesel production are ascribed to social and environmental issues. First, because it is labor intensive and can be produced from different types of raw materials and in several regions in the country. Second, it replaces a very important transportation fuel reducing local polutants like soot, carbon monoxide, and SOx. In addition, it significantly reduces greenhouse gas emissions (Amaral Mendes and Da Costa 2010).

The main risks are ascribed to new technology trends both in the case of different types of feedstocks and the so-called second and third generations, as microalgae, for instance. A good opportunity is to try to explore high valued coproducts in this chain.

16.4 Biodiesel Production Technology

As mentioned elsewhere, the price of raw materials has a strong influence on the final cost of production. In general, more than 80 % of the cost is based on this price (Shi and Bao 2008). In order to reduce this cost, efforts are based on cheaper feedstocks and process optimization.

16.4.1 Transesterification

Transesterification is a reaction between a vegetable oil and a short chain alcohol like methanol or ethanol to produce monoesters and glycerol. This is a reversible reaction and an excess of alcohol is used to shift the equilibria. Stoichiometrically, this reaction involves 3 mols of alcohol to each molecule of triglyceride, producing 3 mols of esters and 1 molecule of glicerol. Industrially, at least 6 mols of alcohol is used for each triglyceride molecule in order to obtain a more complete conversion (Fukuda et al. 2001).

From the most studied transesterification catalysts, Brønsted bases and acids are the main ones, with alcoxides and alkaline hydroxides the prefered ones (Suarez et al. 2007).

It is clear in the literature that basic catalysis have operating problems when high amounts of free fatty acids are found in vegetable oil. In this case, soap is produced reducing the yields with associated emulsions. Similar behavior occurs when moisture is in the reaction media. Hydrolysis of esters produce fatty acids, which react with the base catalyst leading to soap and emulsions (Ma and Hanna 1999).

16.4.2 Hydroesterification

Hydroesterification has been presented as a new alternative to biodiesel production. Several studies are conducted on kinetics, catalysts, multiple feedstocks, production costs, and hydroesterification plant instalation (Lima Leão 2007; Gonçalves 2007; Encarnação 2008; Gomes 2009; Leão 2009).

Hydroesterification means a first reaction of triglyceride hydrolysis producing fatty acids and glycerol. Secondly, an esterification reaction, where fatty acids plus methanol or ethanol produce biodiesel and water (Kuss 2012).

Hydrolysis reaction increases the feedstock acidity, thus a fatty acid remotion is not necessary. Thus, any fatty material (vegetable oil, animal fat, used fried oil, brown grease, etc.) can be used in this process with any acidity or moisture content. The ability to use those types of crude feedstocks is the main difference compared to regular transesterification, which always produces soap and reduces yields due to a difficult glicerol/biodiesel separation (Encarnação 2008).

Acid hydrolysis promotes a complete transformation of fatty materials in fatty acids which are converted into biodiesel in the second step. Glycerol does not suffer any contamination due to alcohol or biodiesel contact since it is removed during hydrolysis. Esterification produces biodiesel and water which can be reused in the hydrolysis step (Arceo 2012).

Based on the above mentioned, hydroesterification (hydrolysis plus esterification) is a promising alternative to conventional biodiesel production (Arceo 2012).

16.4.3 Transesterification and Hydroesterification Costs

A large transesterification biodiesel plant usually presents operating costs of about US$70/ton (electricity, steam, chemicals, and labor) (Encarnação et al. 2009). In the hydroesterification process with no homogeneous catalysts and no inorganic acids in the washing step, total operating cost is about US$35/ton. In a medium to large size biodiesel plant (100,000 mton/year), this process costs about US$3.5 million/year in operating costs.

Table 16.3 Transesterification versus hydroesterification comparison

(¢/L)	Transesterification	Hydrolysis + Esterification
Chemicals	4	1
Energy	1	2
Other operating costs	5	3

Source Cruz and Aranda (2011)

Currently, there are several feedstocks that can be used and transformed into an international standard biodiesel with high yields (about 98 %). The transesterification process cannot be applied efficiently to crude feedstocks. Few hydroesterification studies are found in the literature. Lima Leão (2007), who studied hydroesterification of soybean and castor oils obtained high conversions for castor fatty acids esterification (87.24 %) and soybean fatty acids (92.24 %), with niobium-based catalysts (20 %), temperature (200 °C). Chenard et al. (2009) studied the same process using jatropha oil obtaining conversions from 86.60 to 88.35 %.

As about 80 % of biodiesel operating cost is ascribed to feedstock price, hydroesterification allows a significantly better performance in the feasebility of a biodiesel project. In Table 16.3, a comparison between operating costs for hydroesterification and transesterification (in a 50,000 mton/year) is given.

In order to obtain important advances in this growing biofuel demand, new approaches are necessary. Currently, algae in biodiesel research is considered a new frontier in this sector presenting superior yield compared to other conventional plantation. Biodiesel expectations are huge because: (i) algae absorb CO_2; (ii) growing rate is fast; (iii) high lipid content; (iv) can be cultivated in pools, lakes, raceways, and photobioreactors; (v) high yield by acre; and (vi) not considered as a food item. Nevertheless, Brazil should seek an alternative to soybean with higher efficiency, not necessarily ascribed to edible oil prices (Amaral Mendes and Da Costa 2010).

16.5 Conclusions

The approaches in this chapter allow the understanding of the development strategies of biodiesel production and consumption in Brazil, based on technological, economical, social, and environment sustainability assumptions.

It is relevant to pay attention to the rapidly changing industrial capacity to produce biodiesel. Until September 2013, 63 units were authorized to produce this biofuel, with a total nominal capacity of approximately 8 billion L/year. Over 80 % of this capacity is ascribed to social seal companies that are involved with small farmers providing their feedstocks. From 2005 to September 2013, Brazil produced 13 billion L of biodiesel, reducing diesel imports of US$11 billion and contributing positively to the Brazilian Trade Balance.

Finally, it should be emphasized that biodiesel relevance in the Brazilian industry is influenced by a large amount of R&D funding throughout the production chain, ranging from the agricultural stage to the industrial production processes, including coproducts and storage. In this sense, the current tax model gives Brazilian biodiesel a unique feature in the world supported by a biofuel policy with social orientation.

Acknowledgments Special thanks to the companies Caramuru, Olfar, Petrobrás, and ABIOVE for contributions informed by e-mail.

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