

Biofuels in Brazil: An Overview

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ABSTRACT

The demand for food, fuel, and energy resources continues to increase worldwide. Currently, there are many international efforts aimed at finding renewable, sustainable, and environment friendly solutions for these problems. The spiraling price of petroleum and the adverse effects of using nonrenewable resources are major reasons for increased interest in renewable sources of energy. Brazil, the fifth largest and fifth most populated country in the world, has been developing successful initiatives in renewable sources of energy for more than 75 yr. The production and use of ethanol from sugarcane (*Saccharum* L.) is a global model for ethanol production, distribution, and use; therefore, the Brazilian ethanol industry has attracted interest from scientists, producers, and governments of both developed and developing countries. Like ethanol, biodiesel is also receiving increased interest in Brazil, with the source material for biodiesel production varying widely between regions. Several oleaginous species have been used, and others are being investigated as potential sources for biodiesel production. Biodiesel was introduced much later than ethanol in Brazil with the formation of the Brazilian Energy Matrix in January 2005 and a mandatory use of at least 2% (B2) biodiesel by 2008 and 5% (B5) by 2013. This paper presents a view of the historic development of ethanol and biodiesel programs in Brazil, emphasizing the strategic role of plant genetic resources as a pillar to support future improvements through plant breeding.

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Abbreviations: BAP, Brazilian Agroenergy Plan; CTC, Copersucar Center of Technology; FAO, Food and Agricultural Organization of the United Nations; FFV, flexible-fuel vehicle; MAPA, Brazilian Ministry of Agriculture, Livestock and Food Supply; PNPB, National Program of Biodiesel Production and Use; R&D, research and development.

GLOBAL POPULATION GROWTH continues to soar. Estimates are that the population will reach 6.5 billion by the end of 2006 and by 2050, 9.4 billion people will share the Earth's surface (U.S. Census Bureau, 2006). Clearly, the demand for food, fuel, and energy will increase, and limitations worldwide will become more evident, stretching the resources of developed nations. According to the Food and Agricultural Organization of the United Nations (FAO, 2005), fossil fuels are the most important energy source worldwide, with petroleum accounting for more than 35% of the developed world's primary energy consumption. Coal ranks second (~23%), followed by natural gas (~21%), fuel wood, charcoal, and other biofuels (~10%), nuclear energy (7.6%), and hydroelectric (2.7%) and other renewable energy sources, such as geothermal, solar, and wind (0.7%). The four main energy sources directly contribute to greenhouse gases, a primary contributing factor in global warming. Further,

Published in *Crop Sci.* 47:2228–2237 (2007).

doi: 10.2135/cropsci2007.03.0166

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677 S. Segoe Rd., Madison, WI 53711 USA

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petroleum production is controlled by relatively few countries, and the global economy depends highly on oil prices controlled by these few countries.

The escalating price of petroleum and adverse effects of using nonrenewable resources help explain the interest in renewable sources of energy. *Bioenergy* is a term used to encompass renewable energy sources derived directly or indirectly from a photosynthetic process—including organic waste—that may be used to manufacture fuels (CAST, 2004).

Fuels produced from bioenergy sources are termed *biofuels*. Biofuels are fuels of biological origin, such as fuel wood, charcoal, livestock manure, biogas, biohydrogen, bioalcohol, microbial biomass, agricultural waste and byproducts, energy crops, and others (FAO, 2000). The main sources of bioenergy are agricultural residues and wastes, dedicated-energy crops, and wild vegetation (Hazell and Pachauri, 2006). Globally, from 2000 to 2005, 1 million jobs in the renewable energy sector were biofuel related, and world production of ethanol more than doubled and biodiesel quadrupled (Caldwell, 2007).

Brazil is the largest and most populous country in Latin America and ranks fifth in land area and population in the world. The primary energy sources in Brazil are petroleum (38.4%), biomass (29.7%), hydroelectric (15%), and natural gas (9.3%) (Fig. 1). Currently, oil consumption is approximately 1.8 million barrels per day and is expected to grow at 2 to 2.6% per year. To put this in perspective, Brazil's current oil consumption per capita is 4 barrels per year, while in Spain and the United States, these values are 12 and 25 barrels, respectively (IEA, 2006). Brazil is fortunate to have extensive river basins and plateau rivers, which are fundamental for the generation of hydroelectric power, making Brazil the second-largest producer of hydroelectricity in the world after Canada (IEA, 2006).

Globally, reducing our dependency on fossil fuels while maintaining a safe and healthy environment is a high priority. As a sustainable and renewable source of energy, bioenergy will lessen the impact of rising petroleum prices, address environmental concerns about air pollution and greenhouse gases, and improve opportunities for farmers and rural communities (FAO, 2005; Hazell and Pachauri, 2006). Although economic considerations are paramount for global support of biofuels, other factors such as energy security, greenhouse gas emissions, global climate change, rural employment and equity issues, and local air pollution are helping to drive the bioenergy revolution (Moreira, 2006). According to FAO (2005), increased use of biomass for energy could lead to improved economic development and decrease poverty by the generation of jobs and improvements in the lives of rural people.

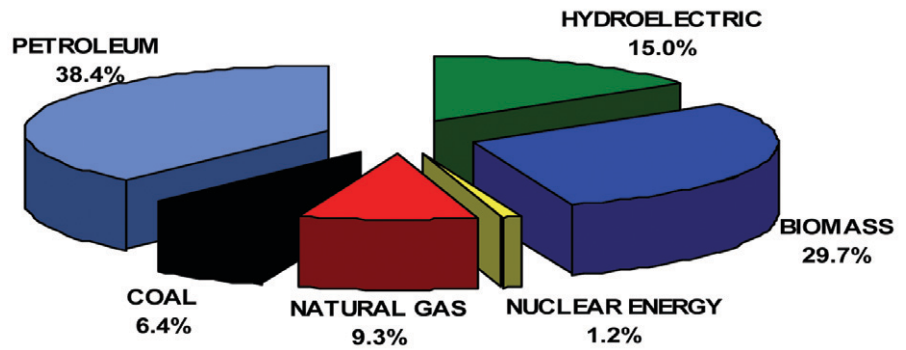


Figure 1. Brazilian Energetic Matrix. Source: MME (2006).

There is growing government and private sector interest in expanding the use of biofuels derived from agriculture and forestry biomass (FAO, 2005). In the transport sector, for example, the use of liquid biofuels has increased over the last 20 yr in Brazil and more recently in Europe, the United States, Japan, China, and India. The sustainability of this sector is highly dependent on economics; bioenergy must be cost competitive with fossil fuels. Brazil currently produces ethanol from sugarcane (*Saccharum L.*) at US\$30 to 35 per barrel of oil equivalent and has been actively encouraging the growth of the biofuels industry for domestic consumption as well as export (Hazell, 2006). Brazil is situated well for this growth because current ethanol production costs in Europe and the United States are about US\$80 and US\$55 per barrel of oil equivalent, respectively. Although government subsidies supported the building of the Brazilian ethanol infrastructure, sugarcane-based ethanol production is currently economically viable largely without government subsidies. This was possible because of economies of scale and competition together with significant increases in agricultural yield (Goldemberg, 2007). While Brazil is producing ethanol for US\$30 to 35 per barrel of oil equivalent, it is estimated that in the United States, ethanol production based on corn (*Zea mays L.*) can only be theoretically profitable at oil prices above US\$45 to 50 a barrel (McCullough and Etra, 2005; De La Torre Ugarte, 2006).

The Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) has coordinated the formation of a consortium involving all sectors of agroenergy partners. The consortium has the following objectives (MAPA, 2006b):

1. to coordinate the activities of governmental agencies, private institutions, companies, financial agencies, universities, cooperatives, and research and development (R&D) institutions involved with agroenergy;
2. to create a network for the exchange and sharing of information and experience in the fields of commerce, investments, and R&D in agroenergy in Brazil and abroad;
3. to implement the National Agroenergy Plan and research activities nationally and internationally; and

- to fund research aimed at increasing efficiency of the production, agro-industrialization and commercialization of agroenergy products and processes in Brazil.

The Brazilian Agroenergy Plan (BAP) was developed to encourage technological research, development, innovation, and technology transfer to guarantee sustainability and competitiveness. An example of how BAP facilitates institutional changes in research is the creation of a new Brazilian Agricultural Research Corporation (Embrapa) unit, Embrapa Agroenergy (MAPA, 2006b). A key to the success of Embrapa Agroenergy is a comprehensive research network extending over many important biofuel commodities throughout Brazil as well as abroad, including Labex (Virtual Laboratories Overseas) and other cooperative programs overseas. Embrapa Agroenergy will join multi-institutional and multidisciplinary bioenergy networks, as well as carry out its own research, to develop innovative agroenergy programs.

Although Brazil has a much longer history of biofuels, the post-1970s period is of particular interest. The development of biofuels in Brazil during this period provides an excellent example of both the volatile nature and the success of biofuel production. The main reason for the success has been the synergies between the sugar market, electricity and heat production, institutional support, and geography (Moreira, 2006). Brazil's location in the tropical and subtropical zones of the world ensures intense solar radiation and a year-round water supply for bioenergy production. In addition, the vast untapped land mass allows new lands to be used for bioenergy production without reducing the farm area devoted to food production (MAPA, 2006b). The ability to serve both sectors, food and bioenergy production, gives flexibility in the marketplace, as evidenced in 2006 when the use of the Brazilian sugarcane production was split almost equally between sugar and ethanol (Fig. 2).

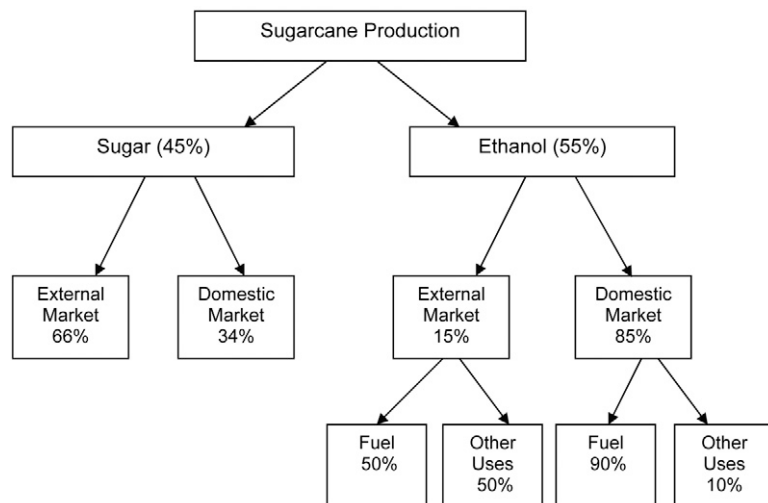


Figure 2. Uses of sugarcane in Brazil 2006. Source: UNICA (2007).

BRAZIL'S ETHANOL HISTORY

Ethanol production in Brazil has a long, interesting, and turbulent history. It is a story compounded by both national and international factors and is complicated by dependence on a raw material, sugarcane, that has products in two commodity groups, fuel and sugar. These two products compete in a marketplace heavily controlled by external players for the raw material. The production of ethanol in Brazil, therefore, serves as an excellent case study for ethanol production elsewhere, such as corn-based production in the United States and sugar beet (*Beta vulgaris* L.)-based in France. In Brazil, as elsewhere, building the infrastructure for the industry depended on subsidies to allow the product to compete with a widely fluctuating external fuel source, oil. The price of petroleum is beyond the control of the national markets yet greatly influences the response of the internal markets. Similarly, the market forces that play on the availability and cost of raw materials depend not solely on the price of alcohol, or oil per se, but also on the widely fluctuating value of the alternative use for the raw materials, sugar in the case of sugarcane and sugar beet and animal feed in the case of corn.

Sugarcane is thought to have been introduced into Brazil in the fourteenth century. By the seventeenth century, Brazil had become the world's major source of sugar as a result of large sugarcane plantations in northeastern Brazil. Although surpassed by coffee in the nineteenth century as the largest valued agricultural crop in Brazil, sugarcane continued to be a major agricultural product and in 2005 ranked fourth (behind cattle, soybeans [*Glycine max* (L.) Merr.] and chicken) in value to Brazilian agriculture.

The alcohol industry in Brazil was initiated and driven by high oil and fluctuating sugar prices. The production of alcohol in Brazil was highly regulated and heavily subsidized until the 1990s. In 1999 alcohol production in Brazil was virtually liberated from government regulation and is just now enjoying a comfortable resurgence. Progress made in Brazil has been incredible. During the 30-yr period since the initiation of the Brazilian ethanol program—ProÁlcool—ethanol production has increased 30 times, yield per hectare has increased by 60%, and production costs have declined by 75%. According to Berg (2004), ethanol has been promoted because of its positive net energy balance; that is, the energy contained in a tonne of ethanol is greater than the energy used to produce this tonne. Further, Segundo et al. (2005) showed that the low amount of nitrogen fertilizer used by sugarcane, together with technological improvements, has led to an energy balance for sugarcane ethanol of one unit fossil fuel used for eight units biofuel produced.

Although the history of alcohol production in Brazil has been reviewed numerous times, we highlight important factors in Brazil's ethanol history to serve as a baseline, reminder, and education for other countries in light of increased demand for ethanol and the

growing interest globally in new feedstocks. It is our hope that understanding the factors influencing the Brazilian program will aid others in their quest for energy sustainability. What follows is a detailed history on how Brazil has become a model country for the use and production of ethanol.

Pre-ProÁlcool: 1930 to 1975

Brazil's governmental interest in ethanol began in 1931 with the construction of the Instituto do Açúcar e do Álcool (Institute of Sugar and Alcohol) and the adoption of legislation that allowed blends of ethanol in gasoline (gasohol) of up to 40% (E-40). At this time, the Brazilian sugarcane industry was encouraged to produce as much ethanol as it could. The legislation was intended to decrease oil imports. It is important to note that even as early as the 1930s, Brazil had a huge imbalance of trade due mainly to the importation and use of oil. Unfortunately, for a variety of reasons, attempts to decrease oil imports by the use of gasohol were not successful during this early period.

In the 1970s, oil prices reached record highs, doubling Brazil's oil import payments by 1974. These increased payments were a prime driver in changing the political will to enhance and support a strong ethanol industry within Brazil. The 1960s and 1970s in Brazil were a time of strong economic growth under a military regime. The regime recognized the importance of maintaining the economic growth and that decreased energy consumption would be devastating to this growth. Superimposed on this was the political clout of the powerful sugarcane growers and sugar processors, who were looking for alternative markets to help sustain the industry during times of highly fluctuating sugar prices. Thus, both internal national and external international pressures led to the creation by the Brazilian government of the National Alcohol Program, better known as ProÁlcool on 14 Nov. 1974.

ProÁlcool: 1975 to 1985

The success of ProÁlcool was mainly the result of very strict controls on supply and demand, which were both stimulated and adjusted through a centralized control system. In 1975 annual goals for ethanol production were set at 3 billion L by 1980 and 7 billion L by 1985. This was achieved through several programs to stimulate the growth of infrastructure and research to drive efficiency improvements in all phases of the process. Incentives included the following (Wall Bake, 2006):

1. Banco do Brasil providing low interest loans (<25% annual percentage rate) for increased distillery capacity and processing infrastructure. This was highly successful as the rush for these subsidized projects was huge.
2. Under ProÁlcool alcohol prices were regulated by the government and production quotas were set to prevent overproduction. Ethanol produc-

ers were guaranteed that the state-owned oil company, Petrobras, would purchase, for a fixed price, all ethanol produced under the quota system. This provided two key elements for alcohol producers: a market for all production and a fixed price, with provided a confidence in the system to spur further growth.

- c. Because ethanol competed directly for the raw material used for sugar production, a final element in controlling the supply chain was to impose export controls and production quotas on sugar. This provided the added confidence needed for sugarcane growers and completed the cycle of control from field to market.
- d. To drive improvements in the system and to ensure all ethanol production sectors would reap the benefits of research, the government also invested heavily in research to reduce costs and increase production.

In the late 1970s, sugarcane growers, as well as the alcohol and sugar interests, became increasingly wary of the dependency on government subsidies for long-term sustainability. Thus, in 1979 the industry founded the Cooperative of Sugar, Alcohol and Sugarcane Producers, or Copersucar. The Copersucar Center of Technology (CTC) rapidly became the centralized location and coordinator for subsidized research in breeding, milling, and fermentation. By virtue of CTC's structure, improvements were integrated throughout the industry.

Another important factor was the development, in the late 1970s, of the Otto-cycle engines, which could run on 100% (E-100) alcohol. To further encourage development and use by making the ethanol cars competitive to consumers, the government placed a lower tax on ethanol-fueled cars than on gasoline-fueled cars. In the early 1980s, the government also decreased the yearly license fee on ethanol cars to further spur demand. Although consumers were initially wary because of early technical issues, by 1984, 96 percent of all new cars sold in Brazil were ethanol fueled.

The challenge for the central government was to balance supply and satisfy demand, while sustaining general economic growth in the country. Huge infrastructural demands were met by government subsidies. This challenge occurred during a period when inflation rates were raising to extreme levels. In 1980 inflation in Brazil was estimated to be 110% (Bresser-Pereira, 1990). Subsidies and tax incentives by the government were estimated to have paid for up to 80% of all the investments made for alcohol production and distribution. Coupling the extreme inflation rates with the low interest rates of the late 1970s and 1980s, it is not surprising that there was great enthusiasm for investment in the alcohol energy sector. The governmental also financed distribution of ethanol by installing ethanol pumps at every Petrobras station throughout the country.

High petroleum prices throughout the 1970s maintained public confidence and optimism about biofuel substitution for fossil fuels. This is illustrated clearly by the number of ethanol-fueled cars purchased in Brazil. During this period, the CTC focused on research to improve sugarcane varieties, increase milling capacities, increase extraction rates, and improve fermentation and distillation processes. By the end of this 10-yr period, continuous fermentation had increased capacity of the distilleries four- to sixfold.

Political, Economic, and Consumer Uncertainties: 1985 to 1995

The Brazilian economy had serious problems throughout the 1980s. The inflation rate in 1985 reached 235%, after triple-digit inflation for most of the previous five years. Politically, the country was in turmoil as it shifted away from a military regime toward democracy. The cost of running the ethanol program was increasingly high in a time when global oil prices were quite low. Public confidence in ProAlcool waned.

The government had to shore up the Brazilian economy with dwindling resources. Ethanol production was increasingly expensive for the government because the industry was established on subsidies that were needed to sustain the program. But the government could no longer afford this. Funding for R&D decreased, which slowed improvements and reduced efficiency. The government then set the guaranteed price of alcohol below production costs in 1986–1987, which placed a burden on the industry that it was not prepared to bear. Alternative uses for sugarcane increasingly looked more favorable with strengthening world sugar markets. Finally, sales of ethanol cars plummeted with the elimination of lower tax rates for ethanol cars, a clear reflection of lost consumer confidence.

In 1988 Brazil drafted a new constitution, beginning a period when all permanent subsidies were to be phased out. This was followed by the privatization of the steel, mining, and energy sectors. ProAlcool was officially terminated.

Early foresight within the sugarcane, sugar, and alcohol industry set the industry in a good position to respond quickly to lost subsidies. The Copersucar cooperative had already initiated programs to survive without government subsidies, and the central-south region already had significantly lower production costs than the rest of the nation. With the lowering of sugar export quotas, the growers and processors could quickly switch from ethanol to sugar production, and the increased exports made Brazil a leader in the global sugar market. Gasohol blends increased from E-10 to E-20, which protected the alcohol market from complete collapse.

Free-Market Economy: 1995 to Present

The Brazilian economy recovered when inflation was brought under control in the early 1990s. All government

regulation of the ethanol industry per se ended in 1999, yet the government retained regulatory authority over gasohol blending rates. The government also continued to support research central to the industry, as illustrated by its support of the sugarcane genome project (<http://sucet.cbmeg.unicamp.br/en>). This effort will be of future benefit for the identification and integration of traits for disease and insect resistance, drought tolerance, sugar content, and increase of biomass. Historically, there has been an intense sugarcane breeding program in Brazil, where 550 varieties were developed and 51 varieties released since 1995. Currently, 20 varieties account for 70% of the total planted area (Macedo and Nogueira, 2004).

Under deregulation the sugar and alcohol industries were not without problems. A grossly overestimated demand, high harvest rates, and high sugar prices led to overproduction of both sugarcane and alcohol in the late 1990s. The 1998–1999 growing season was called the “super harvest” due to extraordinarily favorable climatic conditions for sugarcane production. The Brazilian overproduction had a profound effect on global sugar markets, causing a decline in sugar prices. These factors led to a 30% reduction in Brazilian sugarcane production in the following year, 1999. Sugar and ethanol production plummeted to 1985 levels.

In the early 2000s, oil prices began to rise making ethanol production once again marginally profitable and competitive with gasoline prices. Interest in ethanol-fueled cars was renewed but was still low compared with gasoline cars. The development in Brazil of flexible-fuel vehicles (FFVs), cars capable of running on gasoline, ethanol, or any combination of both fuels, renewed customer interest in biofuels. It allowed customers a choice of fuels based on availability, cost, or performance. Flexible-fuel vehicles in Brazil captured 20% share of the new-car market during the first year of rising oil prices. At the beginning of 2006, about 75% of new cars manufactured in Brazil were FFVs (MAPA, 2006b; Moreira, 2006), which cost no more than conventional cars. This technology put Brazil in a leadership role in the production and economical use of biofuels (MacDiarmid and Venancio, 2006). Brazil's FFV fleet is the only one in the world that can use 100% of either gasoline or ethanol (IEA, 2006).

Brazil remains the world's largest producer of sugar (Marris, 2006; Wall Bake, 2006). In 2006 Brazil had approximately 5 million ha of land in sugarcane production, which yielded approximately 26 million t of sugar. Production for food and fuel do not compete for land as sugarcane occupies only 10% of the total cultivated land and only 1% of total land available for agriculture (Goldemberg, 2007).

Eighty-five percent of the sugarcane grown in Brazil is grown in the central-southern region, with 60% of the production from the state of São Paulo. Most sugarcane production is based on a “ratoon system,” where plantations are established from vegetative parts, with the first harvest within 12 to 18 mo, followed by regeneration from

the existing plants for subsequent yearly harvesting. Under a ratoon system, yields decline ~15% in second year and 6 to 8% each year thereafter. Of greater importance however, is the rapid decline in total reducible sugars after harvesting in the cane. Therefore, time from harvesting to processing is extremely critical in the production equation.

In addition to being the world's largest sugarcane and sugar producer, Brazil is also the world's second-largest ethanol producer. In 2006 more than 17 billion L yr⁻¹ of ethanol were produced (Table 1), with an energy equivalent of 1.5 million barrels of oil. Brazil also has the least oil dependent fleet of vehicles in the world. Small-car sales in Brazil are led by FFVs, a factor contributing to the renewed interest in the production of ethanol in Brazil (Marris, 2006). The use of ethanol has less impact on the environment than conventional gasoline engines (Berg, 2004), and by the elimination of lead and the use of ethanol, Brazil has reduced its carbon emissions significantly (Langevin, 2005).

Interest in ethanol processing plants continues in Brazil. In 2005 there were 320 sugar and alcohol mills with a total processing capacity in excess of 430 million t of sugarcane. Together they can produce up to 20 million t of sugar and 18 billion L of alcohol (MAPA, 2006b). In addition, acreage planted to sugarcane is on the rise, with a projected harvest of 570 million t by 2010, compared with 430 million t in 2005. Between 2006 and 2010, about 90 new sugar mills will become operational, and old refineries will be expanded to become more productive (Moreira, 2006).

As long as oil prices are unstable, alternative fuels such as alcohol will have a place. They are better for the environment, provide a better balance with greenhouse gases, are renewable, and can be cheaper. The Brazilian experience, however, highlights the need for growers to be continually aware of changing externalities and for producers to rely on markets rather than government subsidies. In Brazil the outlook for ethanol production remains optimistic because of a large sugarcane growing potential, the competitive advantage of ethanol due to environmental concerns, the investment into the development of ethanol-powered cars and finally, the long history of ethanol and sugarcane. Since 1975 ethanol has displaced more than 280 billion L of gasoline and saved more than US\$65 billion in the cost of oil imports (Moreira, 2006).

BIODIESEL

Like ethanol, biodiesel has received increased interest as a biofuel. Because of the increased price of petroleum and environmental concerns worldwide, several countries are looking for alternatives to petroleum-based diesel. Research on the use of vegetable oils as a diesel fuel has been intense during periods of

petroleum shortages such as World Wars I and II and the energy crisis of the 1970s (Duffield et al., 1998).

The European Union is currently the global leader in biodiesel production and use, with Germany and France accounting for 88% of world production, followed by the United States, which produces 8% of global production (Hazell and Pachauri, 2006). In the United States, biodiesel production has increased from 1.9 million L (0.5 million gal) in 1999 to 284 million L (75 million gal) in 2005, and it is on track to reach 946 million L (250 million gal) by mid-2007. Commercial biodiesel plants increased from 22 facilities in 2004 to 76 facilities in 2006 (Caldwell, 2007). In the United States, biodiesel has been used principally in urban buses and government vehicles.

Various raw materials such as refined, crude, and frying oils, as well as various technologies (Marchetti et al., 2007), are currently used to produce biodiesel. Advantages of biodiesel are that it is a natural, renewable, biodegradable, nontoxic fuel that produces less pollution than petrodiesel (Wassell and Dittmer, 2005; Marchetti et al., 2007). However, to be profitable, biofuels need to provide net energy gain, be environmentally friendly, be cost-competitive, and be produced in sufficient quantities without reducing food supplies (Hill et al., 2006).

Brazil's Biodiesel History

When the diesel engine was invented by Rudolph Diesel in 1895, it became possible to use vegetable oil as fuel. When Brazil initiated programs to study and develop alternative and renewable fuels in the 1930s, it became a pioneer in biodiesel research, and in 1980, the Federal University of Ceará obtained the first Brazilian patent for biodiesel processing. The use of oleaginous plant species for biodiesel production in Brazil was first proposed in 1975, coinciding with the initiation of ProAlcool. The biodiesel initiative resulted in a program titled Pró-Óleo, or the Production of Vegetable Oils for Energy Purposes. The objective of Pró-Óleo was to generate a surplus of vegetable oil to make the production costs of biodiesel competitive with petroleum. Pró-Óleo's initial goal was to develop a diesel fuel based on mixing 30% vegetable oil with diesel oil, with the eventual replacement of petroleum diesel with biodiesel (MAPA, 2006b).

Table 1. Statistics for Brazilian sugar and alcohol.

	Crop Year				
	2000–2001	2002–2003	2004–2005	2005–2006	2006–2007
Sugarcane production (million t) [†]	326.1	364.4	416.3	457.9	483.8
Harvest area (million ha) [†]	4.8	5.1	5.6	6.2	6.5
Productivity (t ha ⁻¹) [†]	67.9	71.3	73.9	74.0	74.4
Sugar production (million t) ^{†‡}	16.0	22.4	26.6	26.7	29.2
Alcohol production (billion L) ^{†‡}	10.5	12.5	15.2	17.2	18.8

[†]Source: IBGE (2006).

[‡]Source: MAPA (2006a).

Table 2. Brazilian biodiesel production in 2006 and 2007.[†]

Facilities (no.)	Production capacity	
	2006	2007
	—million L—	
Installed and operational (5)	48.10	48.10
Installed pending operational approval (14)	125.60	125.60
Extension of installed units (5)	146.80	146.80
Projects in the design stage (16)	380.00	811.00
Total	700.50	1131.50

[†]Source: MAPA (2006b).

The 1980s were a time of extreme financial difficulty in Brazil, with triple-digit yearly inflation. Unlike the ProÁlcool program, Brazil did not have a strong long-term strategic plan for biodiesel, and because Pró-Óleo did not receive sufficient financial support to grow and thrive, it stalled. While R&D efforts continued on a small scale, no significant progress with biodiesel occurred until 2002, when the Ministry of Science and Technology initiated the Brazilian Program for Biodiesel Technological Development (ProBiodiesel). The National Program of Biodiesel Production and Use (PNPB) was established two years later, in December 2004. In 2005 the first biodiesel processing plant was established in the state of Minas Gerais, using soybean as the vegetable oil source (Rathmann et al., 2005). These programs were a result of high oil prices, a growing demand for fuels from renewable sources, Brazil's potential to produce biofuels, and regional efforts to generate new jobs, increase income in rural areas, reduce regional inequalities, and contribute to the improvement of the environment.

The PNPB defined biodiesel as a fuel obtained from mixtures of fossil diesel and alkyl esters of vegetable oils or animal fat. Technically, biodiesel is the alkyl ester of fatty acids, made by the transesterification of oil or fats, from plants or animals, with short chain alcohols such as methanol or ethanol (Pinto et al., 2005). Glycerol, a by-product of biodiesel production, is used in pharmaceuticals, cosmetics, toothpaste, paints, and other commercial products (Duffield et al., 1998).

Brazil is currently facing challenges to reach goals established in January 2005 by the PNPB (Law #11.097), and introduced into the Brazilian Energy Matrix with a mandatory use of at least 2% (B2) biodiesel by 2008 and 5% (B5) by 2013. The National Petroleum, Natural Gas and Biofuels Agency (ANP) is evaluating several requests for biodiesel facilities (Table 2), and with the opening of the proposed new biodiesel plants, the country's production capacity will be sufficient to meet the 2008 goals. However, huge increases in processing will be needed to meet the legal requirement of 5% biodiesel by 2013 (MAPA, 2006b).

To meet these goals, the Brazilian government has engaged small farmers and producers from the poorest regions in Brazil to participate in the biodiesel value chain and has offered taxes incentives to firms that purchase oil-produc-

ing crops grown on small farms. Overall, biodiesel producers that acquire raw material from family farmers are eligible for tax reductions of up to 68%. If firms purchase palm (*Elaeis guineensis*) oil in the north region or castor (*Ricinus communis*) oil in the northeast and in the semi-arid region from family farms, the tax reductions may be as high as 100%. If firms purchase from producers who are not family farmers, the maximum tax reduction they receive is no greater than 31%. To guide oil production and purchase from small family farms, the government established the Social Fuel Stamp Program. This stamp is issued to biodiesel producers based on two requirements: (i) the producers and processors need to purchase a minimum percentage of their raw materials from family farmers, 10% from the north and midwest regions, 30% from the south and southeast, and 50% from the northeast and the semiarid region; and (ii) the producers need to provide technical assistance and sign contracts with family farmers establishing deadlines and conditions for the delivery of the raw material at predetermined prices (<http://www.biodiesel.gov.br/>).

Brazil's agriculture is facilitated by a warm climate, regular rainfall, plenty of solar energy, almost 13% of the potable water available on earth, and 388 million ha of fertile, arable land with at least 90 million ha not yet explored for agriculture. Several oleaginous species have been used for biodiesel production (Table 3), and others are being investigated (Table 4) as potential sources for biodiesel in Brazil.

The source material for biodiesel production in Brazil varies widely among regions. Soybean, *Helianthus annuus* (sunflower), *Gossypium hirsutum* (cotton), *Ricinus communis* (castor bean), and *Brassica* spp. (colza) are grown in the south, southeast, and central regions; *Elaeis guineensis* (African palm), *Attalea speciosa* (babassu), soybean, and castor bean are found in the northeast and north regions. Soybean is currently the single-largest source for biodiesel production. Bilich and DaSilva (2006) evaluated five oleaginous species to identify which would have the greatest potential for biodiesel production in Brazil using the following criteria: oil percent, harvest period, oil yield (t ha⁻¹), grain yield (kg ha⁻¹), production costs, and oil price. Soybean ranked number one, followed by African palm, canola (*Brassica* spp.), castor bean, and peanut (*Arachis hypogaea*).

THE STRATEGIC ROLE OF GENETIC RESOURCES

Brazil is a large country with climates from tropical to subtropical. It therefore relies heavily on its crop genetic resources as the basis for plant breeding programs. Currently, sugarcane breeding programs are performed by two private (Copersucar and Canavialis) and two public institutions (Ridesa, formerly Planalsucar; and Instituto Agronômico). During the 1970s and 1980s, these programs established a solid base for future needs. Copersucar's germplasm bank has more than 3000 sugarcane accessions

(Macedo and Nogueira, 2004). Most are *Saccharum officinarum*, but the collection also includes several wild species such as: *S. spontaneum*, *S. robustum*, *S. barberi*, and *S. sinense*. In addition, Copersucar has its own quarantine station, where new germplasm is annually incorporated from breeding programs around the world.

The USDA Soybean Germplasm Collection contains approximately 21,000 accessions of soybean, which exhibit a wide range of oil content from 8 to 24%. This year, the entire soybean collection from the USDA will be exchanged with Brazil as a result of a Labex–USA collaborative effort between USDA Agricultural Research Service and its Brazilian counterpart, Embrapa. This collaboration is focused on genetic resources and has a goal of optimizing the management of gene banks in both countries, while fostering and benefiting from the exchange of information, technology, and germplasm (McGinnis, 2007).

The development of high-quality high-yielding cultivars is critical for agribusiness. Breeding success depends on using the genetic diversity conserved in germplasm collections. A new paradigm is emerging with the integration of biotechnology and genomic sciences for the conservation and use of genetic resources. These resources are strategic factors for the development of nations, such as Brazil, that have agribusiness as a strong and competitive area of development.

Today, using genomic sciences and high-throughput analytical procedures can quickly screen large numbers of germplasm accessions in a timely manner for specified agronomic traits. Advances in structural and functional genomics, based on high-throughput technologies (DNA sequencing, genotyping) and bioinformatics (data management, search of specific sequences by powerful algorithms), offer huge advantages, especially as data are deposited in public databases and linked to germplasm accessions in germplasm banks. Such information is invaluable for targeting collections for screening and the isolation of genes associated with the genetic control of complex traits (association genetics based on germplasm collections). Prebreeding activities will improve the information available on accessions maintained in germplasm banks and reduce the gap between available genetic resources and breeding programs (Nass and Paterniani, 2000). The Consultative Group on International Agricultural Research (CGIAR) Challenge Generation Program uses advances in molecular biology, in concert with crop genetic resources to create and provide new plants that meet farmers' needs (<http://www.generationcp.org/index.php>).

Like plant genetic resources, microbial genetic resources will increasingly receive interest as part of the chain to develop cellulosic biofuels. According to Himmel et al. (2007), microbial cells will be expected

Table 3. Characteristics of the main oleaginous crops for biodiesel production.[†]

Crop	Botanical source of oil	Oil contents	Brazilian harvest	Brazilian yield
		%	mo y ⁻¹	t oil ha ⁻¹
African palm (<i>Elaeis guineensis</i>)	Seed	22.0	12	3.0–6.0
Avocado (<i>Persea americana</i>)	Fruit	7.0–35.0	12	1.3–5.0
Babassu (<i>Attalea speciosa</i>)	Seed	66.0	12	0.1–0.3
Castor bean (<i>Ricinus communis</i>)	Grain	45.0–48.0	3	0.5–1.0
Coconut (<i>Cocos nucifera</i>)	Fruit	55.0–60.0	12	1.3–1.9
Colza/Canola (<i>Brassica</i> spp.)	Grain	40.0–48.0	3	0.5–0.9
Cotton (<i>Gossypium hirsutum</i>)	Grain	15.0	3	0.1–0.2
Peanut (<i>Arachis hypogaea</i>)	Grain	40.0–43.0	3	0.6–0.8
Soybean (<i>Glycine max</i>)	Grain	18.0	3	0.2–0.6
Sunflower (<i>Helianthus annuus</i>)	Grain	38.0–48.0	3	0.5–1.9

[†]Sources: MAPA (2006b); Cadernos NAE (2005).

Table 4. Species under investigation as sources for biodiesel production in Brazil.

Species (common name)
<i>Acrocomia aculeata</i> (macauba palm)
<i>Astrocaryum murumuru</i> (murumuru)
<i>Astrocaryum vulgare</i> (tucumã)
<i>Attalea geraensis</i> (Indaiá-rateiro)
<i>Attalea humillis</i> (pindoba)
<i>Attalea oleifera</i> (andaiá)
<i>Attalea phalerata</i> (uricuri)
<i>Caryocar brasiliense</i> (pequi)
<i>Cucumis melo</i> (melon)
<i>Jatropha curcas</i> (pinhão-manso)
<i>Joannesia princeps</i> (cutieira)
<i>Licania rigida</i> (oiticica)
<i>Mauritia flexuosa</i> (buriti palm)
<i>Maximiliana maripa</i> (inaja palm)
<i>Oenocarpus bacaba</i> (bacaba-do-azeite)
<i>Oenocarpus bataua</i> (patauí)
<i>Oenocarpus distichus</i> (bacaba-de-leque)
<i>Paraqueiba paraensis</i> (marí)
<i>Sesamum indicum</i> (benneseed)
<i>Theobroma grandiflorum</i> (cupuassu)
<i>Trithrinax brasiliensis</i> (carandaí)
<i>Zea mays</i> (corn)

to conduct multiple conversion reactions with high efficiency. To achieve this, we will need to acquire a deeper understanding of cellular and metabolic process. Certainly, efforts in the enhancement of microorganisms are needed worldwide for prospective new sources for biofuel production.

POINTS TO CONSIDER

To improve the efficiency of biofuel production, the United States is financing research in numerous areas in the conversion of cellulose to ethanol. Cellulosic ethanol production

will expand the types and amount of available feedstocks, create new jobs, and provide significant reduction in greenhouse gas emissions (RFA, 2006; GEC, 2006). One specific goal of the Biofuels Initiative in the United States is to accelerate research to make cellulosic ethanol cost competitive by 2012 (Herrera, 2006). Several laboratories are engineering new microorganisms to improve pathways related to lignocellulose degradation and subsequent steps to turn it into fuel (Schubert, 2006). In this effort, the USDOE established the project Genomics: GTL Program (USDOE, 2005). This project is using systems biology, which is based on high-throughput technologies and computational modeling, to aid in our understanding of biological processes related to biofuel production (USDOE, 2006), such as fuel production from lignocellulosic components of biomass (CAST, 2004; Koonin, 2006). Farrell et al. (2006) pointed out that many important environmental effects of biofuel production are still poorly understood, and that large-scale use of ethanol for fuel will require cellulosic technology. These R&D efforts can open enormous opportunities for the use of wood and other biomass feedstocks for ethanol production (Goldemberg, 2007).

Energy and climate change are issues we will face over the next decade, and the technologies used 100 years from now will rest on fundamental research that begins today (Whitesides and Crabtree, 2007). As a leader in biofuel production, Brazil has been promoting a global market for biofuels by trying to diversify the world's production of biofuels and improving conditions in rural communities, particularly in developing countries (Caldwell, 2007).

Brazil has been working with renewable sources for energy production for over 70 years. However, Brazil's programs must be continually updated and reviewed for future needs. Comparing the ethanol and biodiesel programs, it is clear that early ethanol production in Brazil was driven primarily by economic factors. In contrast, the recent efforts in biodiesel production involve at least three driving forces: (i) economic—the influence of oil prices, but this time the Brazilian dependence in foreign oil is much less of a factor; (ii) social—the need to generate jobs and new opportunities for permanent settlement of families in the countryside; and (iii) environmental—to produce a sustainable, renewable, and friendly fuel.

The BAP (MAPA, 2006b) highlighted several new challenges for Brazil in the future. The main research challenges for ethanol include

1. the use of biotechnology to introduce new characteristics such as pest resistance, drought, soil acidity and salinity tolerance, and increase nutrient uptake efficiency;
2. the promotion of agroecological zoning for sugarcane in the new expansion areas;
3. the development of technologies to promote symbiotic nitrogen fixation, and

4. the development of new products and processes based on alcohol chemistry and the use of sugarcane biomass.

For the biodiesel program, the main research challenges include

1. the evaluation of additional oleaginous plant species with increased energy density and broad edaphic and climatic adaptation;
2. the promotion of agroecological zoning of conventional and potential oleaginous species;
3. the development of cultivars, varieties, and hybrids of conventional and potential species;
4. the development of harvesting and processing systems for improving oil extraction and the use of coproducts and residues; and
5. the use of biotechnological techniques to investigate the introduction of new traits.

Acknowledgments

The authors thank Dr. Christina Walters and Mauricio Antunes for valuable and insightful comments on the paper. This work was funded by institutional sources. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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