Task 40 *Sustainable Bio-energy Trade; securing Supply and Demand*

Deliverable 8

Market Evaluation: Fuel Ethanol

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Summary

Abstract

In recent years it has been observed a rapid growth on fuel ethanol consumption. Many countries have recently set mandates for biofuels but so far the consumption of fuel ethanol has been concentrate in Brazil and USA. Trade of fuel ethanol is estimated as equivalent to about 10% of the world consumption in 2005 and Brazil is by far the main exporter. The most important potential markets of consumer – USA and EU – have trade regimes that constrained the comparative advantages of some producer countries. This paper aims at evaluating the development of fuel ethanol market as automotive fuel up to 2030 and the potential for international biotrade. Based both on forecasts of gasoline consumption (estimated with a simple model) and on targets/mandates of fuel ethanol use it is estimated that the fuel ethanol demand can reach 272 Gl in 2030 (from 33 Gl in 2005), displacing 10% of the estimated demand of gasoline at that year. The analysis was developed explicitly considering fuel ethanol consumption and production in USA, EU 25, Japan, China, Brazil and in the rest of the world (ROW-BR). Then, an exploratory exercise was developed in order to evaluate the potential international trade in 2030. In case of extreme protective policies to preserve the interests of farmers in USA and EU, imported volumes by USA, EU, Japan and China would reach 24 Gl, less than 20% of the estimated consumption of fuel ethanol in these countries/regions. In case USA and EU set quotas equivalent to 30% of their estimated consumption of ethanol, imports would be increased to 45.9 Gl (38% of the estimated consumption). It is estimated that Brazil alone could supply this demand by 2030, but other countries in the world – mostly developing countries – have potential to be large-scale producers and exporters of fuel ethanol during the following 25 years.

Keywords: fuel ethanol; biotrade; international trade; market estimation; biomass.

1. Introduction

This is the final report of Task 40 Deliverable 8 – Evaluation of Markets: Ethanol, developed during the first triennium of IEA Bioenergy Task 40 – Sustainable International Bioenergy Trade: Securing Supply and Demand. Deliverable 8 was lead by Brazil.

Ethanol has many industrial applications (e.g. pharmaceutical, as chemical feedstock, as beverage, etc.), but this report deals exclusively with fuel ethanol market as automotive fuel, currently the fastest growing application. The main aims of this report are to evaluate the development of this market up to 2030 and the potential for international biotrade.

Ethanol can be produced from fossil fuel feedstocks (e.g., petroleum derivatives), by synthesis, or from biomass. The synthesis route evolves dehydration of hydrocarbons (e.g., ethylene) or by reaction with sulphuric acid, to produce ethyl sulphate, followed by hydrolysis. The production routes from biomass are based on fermentation or hydrolysis. Carbohydrate-rich raw materials suitable for ethanol production may be classified into three groups: (i) feedstocks rich on sugar (sugar-beet, sugarcane and molasses), (ii) starches (cassava, cereals, potatoes) or (iii) cellulosic materials (e.g., wood, rice straw, sugarcane bagasse and even waste materials, in general).

From sucrose feedstocks, ethanol is produced from fermentation of sugars. From starches, the feedstock must first be hydrolysed to glucose, followed by a second stage of fermentation to produce ethanol. Cellulosic materials can be converted to ethanol through hydrolysis or gasification (i.e., synthesis gases as an intermediary flow), but these routes of production are not commercially available so far. This report focuses on the production of fuel ethanol from biomass via commercial technologies, from feedstocks rich on sugar and from starches.

2. Driven Forces for Biofuels

Although the forces pushing for ethanol fuel vary considerably, there are some common features: (i) environmental – concern with clean air is a social and political priority throughout the world; for example, the necessity of reducing pollutant emissions and accomplishing targets defined by Kyoto Protocol; (ii) energy security – increasing dependency on imported energy supply, especially in a context of rising of oil prices, is also a general concern, particularly in the EU and USA; (iii) social and economic pressures, e.g., the desire to promote rural development and to create jobs (Rosillo-Calle & Walter 2006).

2.1 Transportation sector and biofuels

Worldwide, there is a growing interest regarding the use of liquid biofuels in the transport sector, being ethanol and biodiesel the best short-term alternatives. Rising oil prices, environmental concerns – including concerns regarding emissions of greenhouse gases (GHG) –, and interests in energy security have driven countries to look to biofuels production, ethanol in special, as a potential solution (BP, 2006a). Other important driven forces have been the concerns regarding the need to stabilize commodity prices and cut down on agricultural subsidies (FAO, 2006).

Regarding biofuels, the main priorities of developed countries are to reduce GHG emissions and diversification of the energy matrix[1], while developing countries tend to put the focus on rural development, jobs creation and saves of foreign currency. Energy security is a priority for most countries (ESMAP, 2005). Another important reason for the recent surge of biofuels is due to the limited spare of refinery capacity that has constrained the oil market in recent years (IEA, 2006a).

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[1] Despite the fact that for most developed countries agricultural issues are still the main driver force. For instance, the benefits to farmers would be a way to reduce costs and market distortions of the existing farm support policies of OCDE countries, that now sums-up US$ 320 billion a year (Hazell and Pachauri, 2006).

In 2004 the global consumption of oil products in the transportation sector reached 1,769 Mtoe (74.1 EJ), of which 872 Mtoe (36.5 EJ) of mineral gasoline and 642 Mtoe (26.9 EJ) of diesel oil. This represented 53% of the total consumption of oil and oil derivatives (total final consumption plus the consumption of the energy sector) (IEA, 2006b). Since 34-35% of the primary energy consumption is supplied by oil, it can be concluded that gasoline and diesel represented in 2004 about 20% of the world energy consumption.

In 2000, the GHG emissions of the transport sector corresponded to 28% of total emissions (estimated as 6.3 $GtCO_2$ on a well to wheels basis[2]). About two-thirds of the GHG emissions are associated to passenger transport, while the rest is from freight transport (IPCC, 2001). In 2003 end-use emissions in the transport sector were equal to 5.1 $GtCO_2$, i.e., 21% of the total energy use emissions (IEA, 2006c).

In a broader sense, mobility is considered one of the fundamental rights of human beings, the basic pillar for the economy and for quality of life. Society has been organized for a century in such a way that without vehicles, mobility is severely constrained. A vehicle is one of the main dreams of most consumers around the world and this largely explains why the automobile and the oil industry have become the largest in the world.

Most studies on energy use in the transport sector demonstrate the growing importance of automobiles in individual transport that will continue in the decades to come. Different energy sources and technologies have been considered, such as biofuels, natural gas, electricity (both from the grid and as electricity produced from fuel cells), hybrid cars, etc. With regard to alternative transport fuel vehicles, the "chicken and egg problem" is what comes first, the infrastructure or the alternative fuelled vehicle? See for example Romm (2006).

An important advantage of biofuels is that the required changes in the existing infrastructure and on the stock of vehicles are minor, including petrol stations. These advantages are even larger when blends of biofuels and fossil fuels are used and if the blends are prepared upstream of the fuel stations. Also for these vehicles the modifications

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[2] Emissions in the fuel cycle as a whole, considering extraction of oil, transport of oil and oil derivatives, refinery, consumption of derivatives, etc.

are also relatively small or unnecessary in case of blends with up 10% ethanol (E10). In USA, for instance, since the 1980s all automakers have covered the use of E10 under their warranties (WSDA, 2006). Required ethanol engine and vehicle modifications are summarised in Box 1. However, the initial costs of producing and using biofuels are still high and a new biofuel industry needs of coordinated investments by farmers, car manufacturers, fuel distributors, etc., to achieve a critical size (Hazell and von Braun, 2006).

Over the past few years more than 30 countries have introduced or are interested in introducing programmes for fuel ethanol (Rosillo-Calle and Walter, 2006). Other countries, but to a lower extent, have done the same regarding biodiesel. Thus, the ethanol experience is so far much more important than with biodiesel, excluding Europe where the prospects for biodiesel use are much better than fuel ethanol due to the availability of the feedstock.

Global ethanol production in 2005 reached 45 billion litres (or 45 Gl), being about 33 Gl[3] for fuel use and the rest for beverage and industrial purposes (FO Licht, 2005; REN21, 2006). Ethanol production for fuel use in 2005 was roughly equivalent to 17.6 Mtoe (0.74 EJ), or approximately 2% of global gasoline consumption; the production of biodiesel was 3.8 Gl, i.e., equivalent to 3 Mtoe (about 0.13 EJ), approximately 0.2% of diesel consumption (IEA, 2006a). Brazil and USA have dominated ethanol production and its use, and both countries were responsible in 2005 for more than 80% of the world production. On the other hand, the main producer of biodiesel is Germany that in 2005 has produced more than 50% of the world production.

2.2 Biofuels for developing countries

In June 2005, the United Nations Foundation launched the Biofuels Initiative aimed at promote the sustainable production and use of biofuels in developing countries. The UN Foundation states "*biofuels have the potential to alleviate poverty, create sustainable rural*

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[3] Different figures on fuel ethanol production have been presented. Values vary between 33 and 37 Gl (i.e., Worldwatch Institute, 2006). General sense all authors quote C Berg or FO Licht as the primary source of information. In this report 33 Gl is used to be conservative. For the purpose of evaluating future fuel ethanol markets, the accurate production in 2005 is not imperative.

development opportunities, reduce reliance on imported oil, and increase access to modern energy services" (United Nations Foundation, 2006). Generally, developing countries have a reasonable good potential for biofuels production due to the availability of land, better weather conditions and the availability of cheaper labour force. Other important issue to be taken into account is that strengthening rural economies is an imperative task for these countries. Obviously each country is case-specific and a careful analysis is required to assess the pros and cons of large-scale biofuels production, particularly competition for land and water for food production and potential pressures on food prices (Hazell and von Braun, 2006)[4]. A study by Smeets et al. (2007) concludes that in Sub-Saharan Africa, the Caribbean and Latin America there is a larger potential for bioenergy production due to availability of agricultural land due either to surpluses or current inefficient agricultural production systems.

Many developing countries are net oil importers (crude oil and/or oil derivatives, especially gasoline and diesel) and for these countries biofuels use can bring the combined benefit of enhancing energy security and of reducing expenses in hard currency[5]. Taking African countries as example, as of 2005 just four countries have concentrated more than 75% of the oil production[6] (BP, 2006b). In addition, in 2003 the energy consumption at the transportation sector represented almost 60% of the total final consumption of oil and derivatives in Africa (IEA, 2006b). More importantly, for some African countries their high dependence on oil imports represents the largest share of their expenses in hard currency (DSD, 2005), which in addition make them extremely vulnerable to price volatility (World Bank, 2006).

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[4] According to the International Food Policy Research Institute – IFPRI, an aggressive biofuel scenario could lead to significant price increases for some food crops by 2020 – about 80 percent for oilseeds and about 40 percent for corn—unless new technologies are developed that increase efficiency and productivity in both crop production and biofuel processing. Combining the demand scenario with productivity improvement and second-generation cellulosic conversion, price increases are softened to about 40 percent for oilseeds and 20 percent for corn by 2020 (von Braun and Pachauri, 2006). The authors conclude that without technologies to improve productivity (and also expand the range of feedstock), in case an aggressive biofuel scenario the prices changes would adversely affect poor people and small farmers.

[5] According to Hunt and Förster (2006), of the world's 47 poorest countries, 38 are net oil importers, and 25 of these import all of their oil. In many smaller and poorer nations, 90 percent or more of the total energy used comes from imported fossil fuels.

[6] Nigeria, Algeria, Libya and Angola.

With biofuels, such dependency could significantly be reduced while, at the same time, allowing these countries to become potential exporters of biofuels in the future in addition to the potential domestic socio-economic benefits.

Biofuels production can also induce spin-off industrial applications and will certainly induce jobs creation. In Brazil, for example, it is estimated that the ethanol program saved 121.3 billion US$ in the 1976-2004 period[7]. Regarding jobs creation, it is demonstrated that the required investment is very low compared to other economic activities (e.g., 10 US$/job in the sugar cane industry, while the correspondent investment in the consumer goods sector is 4 times higher and 20 times higher in the chemical/petrochemical industry (Goldemberg, 2002).

According to UNICA[8] (2006), the ethanol industry in Brazil is responsible for about one million direct jobs, approximately 50% in the sugarcane production. Indirect jobs are estimated to be between to 2.5 to 3.0 million. However, it should be mentioned that this high employment is partly due to low level of mechanization of agricultural activities, as well as poor automation at the industrial site. In the long term, increasing mechanization and automation are inevitable and, in certain degree, desirable. Consequently, the demand for labour in this sector will be considerably reduced. It is worth noticing that work conditions for those who work on sugar cane harvest are really tough[9], and in middle to long term it is not reasonable to consider a large amount of jobs like this as an achievement of fuel ethanol production.

From an environmental perspective, first it should be highlighted the benefits of phasing-out lead from gasoline, as lead has adverse neurological effects (Thomas and Kwong, 2001). Hydrated ethanol has higher octane number than regular gasoline (e.g., > 95 versus > 87, for (RON+MON)/2 (Joseph Jr., 2005)), and its use in blends allows the phasing out of lead at low cost. This would be a very important advantage of ethanol use in countries

[7] US$ 60.74 billion (US$ December 2004) due to the substitution of gasoline in the period 1976-2004. This value was calculated considering interest on the avoided foreign debt (Moreira and Walter, 2005).

[8] Organization of sugar and ethanol producers of State of São Paulo, where the bulk of the production takes place. UNICA uses to present the most reliable data of sugar cane industry in Brazil.

[9] As long as manual harvesting is considered. Essentially, manual harvesting is responsible for the bulk of jobs in the agricultural side.

where lead is still in use, as is the case of many African and some Asian and Latin American countries (Thomas and Kwong, 2001).

Despite some controversy, it is well accepted that automotive use of E10 vis-à-vis E0 contributes to the reduction of tailpipe emissions of particulate matter and carbon monoxide (IEA, 2004) and, as long as RVP (Reid vapour pressure) control is effective[10], reductions on total hydrocarbons and air toxic emissions (especially benzene) can also be achieved (Niven, 2005). For nitrogen oxides emissions, both higher and lower emissions regarding E0 have been reported (Niven, 2005)[11]. However, some studies (e.g., Whitten and Reyes 2004; Nastari et al, 2005) have shown that in the case of ozone formation, in the worst case ethanol is neutral. The advantages regarding emissions are more meaningful if the existing fleet is relatively old or its maintenance is poor, as is the case in most developing countries. With the introduction of more efficient emission control systems in vehicles (i.e., electronic management injection, catalytic converters and canisters) final exhaust emissions are roughly the same despite of the fuel used (Joseph Jr., 2005).

Large-scale use of biofuels is one of the main strategies for the reduction of GHG emissions (IPCC, 2001). Despite the fact developing countries currently do not have biding GHG reduction targets under the Kyoto Protocol there are two main aspects to be considered. First, under the Clean Development Mechanism (CDM), developing countries can sell credits to those with reduction commitments, as far biofuels programs are not business as usual[12]. Considering a typical Brazilian figure of 2.7 kg of CO_2 equivalent avoided per litre of anhydrous ethanol, biofuels use could represent additional income of US$ 0.02-0.05 per litre (on credits in the range US$7-20 per tonne of CO_2 equivalent), value that should be compared with production costs in the US$ 0.23-0.28 per litre range

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[10] RVP is a measure of fuel vapour pressure. In countries where there are standards for VOC (volatile organic compounds) emissions, RVP is controlled. As RVP of E10 can be higher than E0, in order to maintain an acceptable value refiners typically lower the RVP of gasoline that is blended with ethanol by reducing lighter fractions and using other additives (IEA, 2004). Haug (2003) states that the problem of mostly occurs over the first 1% ethanol; above 8%, fuel vapour pressure with ethanol begins to drop again.

[11] Joseph Jr. (2005) states that the emissions of nitrogen oxide before catalyst converter for a typical Brazilian car running with E22 are about 4% higher than an E0. However, after catalyst converter the atmospheric emissions are essentially the same in both cases.

[12] Brazilian ethanol program is not eligible as a CDM project, in the sense it exists for a long time and carbon credits are not essential to make fuel ethanol use feasible.

(Nastari, 2005). Second, climate change effects are supposed to be worst in developing countries and it is important to start acting.

3. Ethanol Experiences and Perspectives

3.1 An overview on fuel ethanol experiences

Brazil has been for decades the world's largest producer and consumer of fuel ethanol, but probably was overtaken by USA in 2006. The most important ethanol producers (all grades) in 2005 were Brazil, USA, China, India and France, responsible for 84% of the world production. As of 2005, Brazil and USA were responsible for more than 70% of the world ethanol production (all grades) (RFA, 2006a).

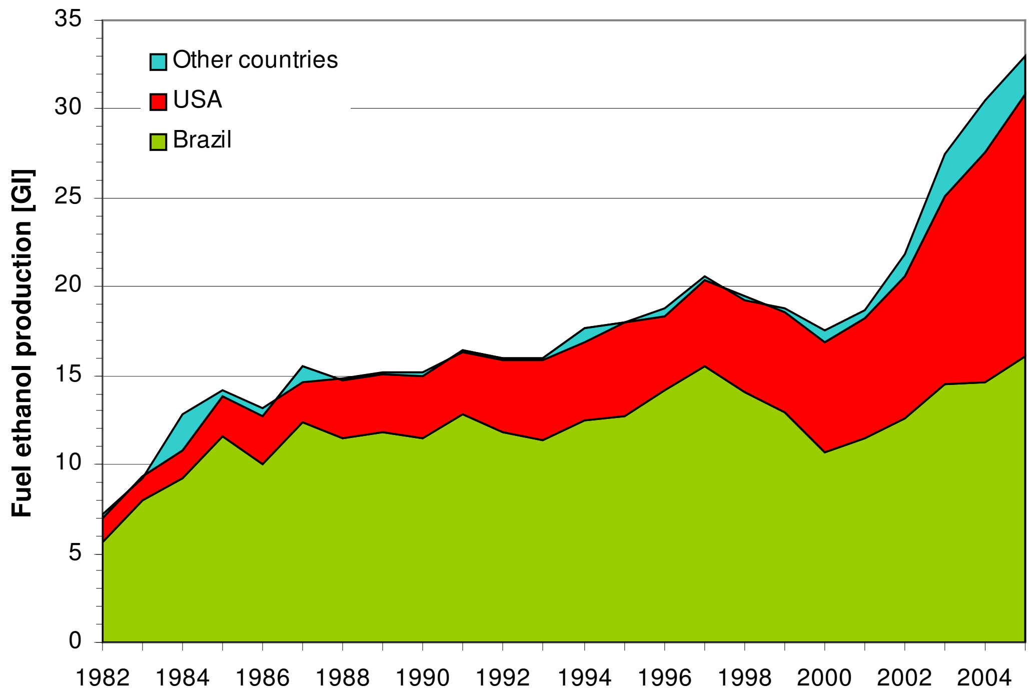
Figure 1 shows the evolution of fuel ethanol production from 1982 to 2005. Production figures are more reliable for Brazil and USA. Prior to 2000 it seems clear there are inconsistencies regarding the total world production caused, among other factors, by the different uses of ethanol and unreliability of statistic information. In 2000, according to Berg (2004), fuel ethanol represented about 60% of the total production (17.3 Gl vis-à-vis roughly 30 Gl), rising to about 73% in 2005 (33 Gl vis-à-vis almost 45 Gl) (REN21, 2006) (RFA, 2006b).

A significant growth of fuel ethanol production occurred after 2000. The average annual growth rates for USA, Brazil and the rest of the world in the 2000-2005 period are presented in Table 1. It can be seen that the growth was significant in other countries but, in absolute terms, the greater growth has been in the USA.

Table 1. World fuel ethanol production in recent years [Gl]

	World	Brazil	USA	Rest of the World
2000	17.58	10.70	6.17	0.71
2005	33.00	16.04	14.78	2.18
Average growth rate [%]	13.4	8.4	19.1	25,2

Source: REN21 (2006) for the world, RFA (2006b) for USA and Brasil (2006a) for Brazil



Source: REN21 (2006) for the world, RFA (2006b) for USA and Brasil (2006a) for Brazil

Figure 1. Fuel ethanol production from 1982 to 2005

The ten largest producers of ethanol (all grades) in 2004 and 2005 are listed in Table 2. Besides USA, ethanol production has grown remarkably in countries where there is an effort to foster the use of ethanol or ethanol derivatives (e.g., ETBE – ethyl tertiary–butyl ether).

Table 2. Main ethanol producers (all grades) in 2004 and 2005

2004	Million litres	2005	Million litres	Growth rates (%)
Brazil	15,413	Brazil	16,500	7.1
United States	13,380	United States	16,214	21.2
China	3,649	China	3,800	4.1
India	1,749	India	1,700	-2.8
France	829	France	910	9.8
Russia	749	Russia	750	0.1
South Africa	416	South Africa	390	-6.3
UK	401	Spain	376	375.9
Saudi Arabia	299	Germany	350	393.0
Spain	299	Thailand	300	305.4

Source: Earth Policy Institute (2006)

Considering the ethanol production in 2005 (all grades), about 60% of the production was based on sugar crops, 30% from grains (mostly corn), 7% corresponded to synthetic ethanol (produced from ethylene, coal, etc.) and 3% from other feedstocks.

As mentioned, the interest in biofuels has increased due to environmental, geo-political and economic factors, including the desire by countries to develop new markets for agricultural products. This push is essentially policy driven, and blending mandates and tax incentives have been used in a large extent (Elobeid and Tokgoz, 2006; Föerster et al. 2006). In 2005-2006, several countries stepped up targets and mandates for biofuels. By the end of 2006, biofuels blending mandates existed at the national level in nine countries while in other four mandates were valid in some states/regions (REN21, 2006)[13]. In all other countries ethanol is blended with gasoline in proportions that vary from 2 to 10% (volume basis). Brazil is

[13] Countries with mandates at national level: Brazil, Colombia, Germany, France, Malaysia, Philippines, Thailand, United States (federal renewable fuel standard), and Dominican Republic. Countries with mandates valid in some regions: India (nine states plus four federal territories), China (nine provinces; cities only in four), Canada (Saskatchewan and Ontario), United States (Hawaii, Minnesota, Montana, Washington, Wisconsin) (REN21, 2006).

the only country using neat ethanol in large scale. The main experiences regarding fuel ethanol use are described bellow.

3.2 Brazilian experience and perspectives

Besides the existence of pure ethanol-fuelled vehicles, all motor gasoline sold in Brazil contains 20-25% ethanol, volume basis (E20 – E25)[14]. Neat ethanol vehicles use hydrated ethanol, while anhydrous ethanol is used for blending with gasoline[15]. In addition, in Brazil flex-fuel vehicles – FFVs – can also be fuelled with hydrated ethanol.

Brazilian experience with ethanol-gasoline blends dates back to the 1930s, but it was in 1975 that the Brazilian Alcohol Program (PROALCOOL) was created aiming at partially displace gasoline in the passenger car segment, at a time when the country was heavily dependent on oil import and gasoline was the main oil derivative consumed.

As of 1979, with the second oil chock, Brazilian government decided to increase production, supporting large-scale production of hydrated ethanol to be used as neat fuel in modified engines. In the 1975-1979 period, ethanol production was accomplished in new distilleries annexed to the existing sugar mills, while from 1979 to 1985 increases in production was achieved through the construction of autonomous distilleries. It is estimated that at that time about US$ 11-12 billion were invested to create the structure able to produce 16 Gl/year.

Despite its success vis-à-vis its main primary goals[16], PROALCOOL has not been exempted of controversy mostly due to the generous financial support given by the government to inefficient producers. In addition, in middle 1980s, with the decline of the

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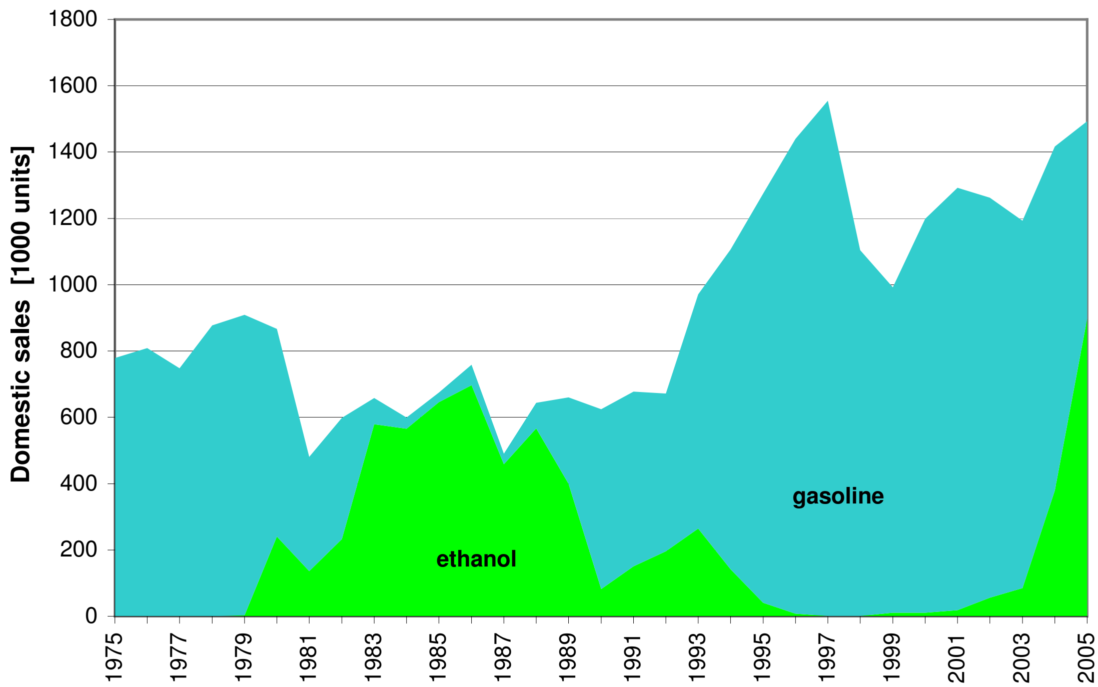
[14] By the end of 2006 all gasoline sold in Brazil was E24. Since 1993 is has been defined by law that the share of ethanol in fuel blend is in the 15-25% range, depending on the conditions of ethanol supply. For instance, the E25 blend that was applied for some years was reduced in early 2006 to E20 (just during some months) due to the increase on hydrated ethanol demand.

[15] In Brazil, National Oil Agency (ANP) is responsible for the regulation regarding technical standards of all automotive fuels. The alcohol content of anhydrous ethanol is specified as 99.3% (volume basis) as a minimum, while the alcohol content of hydrated ethanol can vary in the 92.6-94.7% range. The difference is water content.

[16] Reduction of oil imports, stabilisation of the sugar market, enhancement of Brazilian competitiveness on the sugar market and creation of hundred of thousand jobs.

international oil prices, such criticisms reached new levels. Furthermore, despite efforts towards restructuring of oil refineries, there was a large surplus of gasoline during the 1980s and 1990s, and this was a problem for the Brazilian oil company[17].

The reduction of governmental support caused by the debt crises, together with the lack of vision of many cane producers[18], led to serious ethanol shortages early 1990s. Sales of pure ethanol-fuelled cars dropped from 92-96% during the eighties to about 1,000 new vehicles per year in 1997-1998, as illustrate in Figure 2.



Source: ANFAVEA (2006)

Figure 2 – Sales of new vehicles (automobiles + light trucks) – 1975-2005

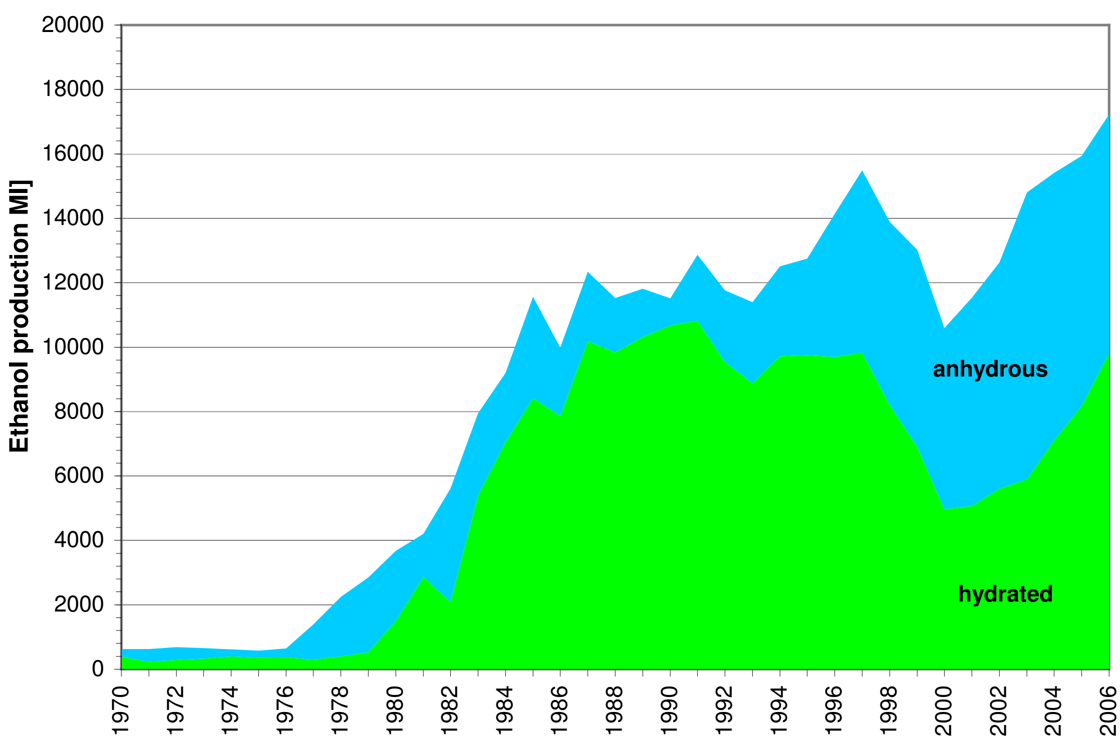
Further, changes also have occurred in the ethanol market, firstly with liberalization of fuel prices to consumers along the 1990s and secondly, by the end of the decade, with full

[17] PETROBRAS, at that time state-owned and now stated-controlled. Due to the lower quality of Brazilian gasoline regarding international standards it was very difficult to commercialise the surplus as gasoline.

[18] At that time prices for sugar in the international market were very high and sugarcane producers had a very short-term strategy.

deregulation of sugarcane industry. However, positive impacts on fuel ethanol demand began to take root after 2001 when, due to a larger price difference between ethanol and gasoline caused mostly because by the reforms –, sales of neat ethanol cars started rising again. More importantly, since 2003, with the launch of flex-fuel vehicles – FFVs – it is observed a boom on sales of vehicles able to run powered by ethanol (see Figure 2). In mid-2006, FFVs have reached 80% on sales of new vehicles.

In comparison with neat ethanol vehicles, the main advantage of the FFVs is that these engines can operate with any fuel mix between gasoline (in Brazil, E20-E25) and pure hydrated ethanol (E100). The success on sales of FFVs and the relative low price of ethanol vis-à-vis gasoline are the reasons why it is predicted that the domestic ethanol market will increase even further in the future. In 2005 ethanol production (anhydrous + hydrated) has reached 16.5 Gl and the estimates for 2006 are 17.2 Gl. Figure 3 shows the evolution of fuel ethanol production in Brazil since 1970.



Source: Brasil (2006a)

Figure 3. Fuel ethanol production in Brazil from 1970 to 2006

PROALCOOL was the program created and supported by federal government aiming at giving conditions for the enlargement of ethanol production and the development of the supply structure, as well as at assuring demand formation. In fact, PROALCOOL no longer exists, as since late 1990s the federal government doesn't have any control over ethanol production and its commercialisation. In Box 2 policy and regulatory instruments applied in Brazil to support large-scale ethanol production are briefly described.

Brazil is the only country in the world with the conditions to quite considerably expand its capacity of ethanol production in short- to mid-term (e.g., land availability, technology, working-force, investment capacity, etc.). Currently some 80 new industrial units are in different stages of construction, compared with 335 units presently in operation. It is expected that ethanol production capacity shall more than double from 2006 to 2015 (Carvalho, 2006). Potentially, Brazil can even expand its ethanol production capacity 8-10 times in the next 20-30 years. Despite its adequate conditions, naturally that it is a challenge to assure that such big expansion can be achieved in a sustainable way.

Ethanol production in Brazil is so far concentrated in State of São Paulo, responsible for 72% of the production in 2006 (Carvalho, 2006). Once the planned expansion production is completed, production will be better distributed countrywide.

3.3 US experience and perspectives

The USA has the world's fastest growing and largest fuel ethanol market, with an estimated production larger than 15 Gl in 2005. The country has reached a two-fold increase in its production capacity in just three years and almost a four-fold increase in nine years. In the past ethanol was used in niche markets in the Midwest, where the production is still concentrated[19]. However, since in the 2006 fuel ethanol is consumed across the country and blended in 30% of the gasoline consumed in USA (RFA, 2006a). It is expected that in 2006 fuel ethanol would be blended in 40% of the gasoline consumed (FO Licht, 2006). Ethanol

[19] The main producers are the states of Iowa, Nebraska, Illinois, South Dakota and Minnesota, with 80% of the online production capacity in early 2006 (16.2 Gl/year) and 76.4% of the total near-future production capacity (RFA, 2006a). In 2006 there were 97 ethanol refineries located in 21 states and 33 under construction that will allow a 40% growth on the production capacity (RFA, 2006b). By 2005 around 80% of the new ethanol output is coming from plants which are not controlled by farmers.

is sold in most states as octane enhancer or oxygenate blended with petrol, and currently covers close to 3% of the USA's gasoline demand (RFA, 2006a).

In recent years fuel ethanol demand has been stimulated by the phasing-out of methyl tetrabutyl ether (MTBE) as octane enhancer that by the end of 2005 was banished in 23 states. A major concern with MTBE is water contamination and its health effects. With the discontinued production of MTBE in May 2006, a market as large as 11.4 to 13.2 Gl was filled by fuel ethanol. Other reasons include concerns with oil prices and external oil dependency.

In August 2005 the US government signed into law the Energy Policy Act of 2005, creating a national Renewable Fuels Standard (RFS) which set targets of 28.4 Gl of renewable fuel to be used in the transport sector by 2012, the vast majority fuel ethanol. As consequence, ethanol production capacity should almost double from 2006 to 2012. During 2006 the US Congress has debated measures to increase mandate levels in 2010 and in 2020 (FO Licht, 2006) that will push demand even higher.

The Energy Information Administration – EIA (2006) – indicates that fuel ethanol consumption should grow almost four-fold in the 2005-2030, reaching 55.3 Gl in 2030. However, by the end of 2006 it was mentioned that USA could set by 2030 a much more ambitious mandate regarding fuel ethanol use – 227 Gl – target that is considered achievable as long as ethanol production from cellulosic material is considered a feasible alternative (Foust, 2006). This 227 Gl target – 60 billion gallons – is further discussed in section 4.3.

In addition to the federal government resolutions, five states – most of them potential large-scale producers of fuel ethanol – have defined local legislation to booster renewable fuels use; this is being consider by many others states. For example, Minnesota, have adopted the target of 20% ethanol blends to take effect in 2013 (RFA, 2006a).

Table 3 illustrates the estimated macro-economic impacts of the RFS in USA by 2012. US farmers are confident that ethanol can contribute more to their well being than increased access to export markets of corn (FO Licht, 2006).

In contrast to Brazil, the main feedstock in the US is corn, with just few units – about five, out more than a hundred plants in 2006 – utilizing other feedstocks, such as beverage waste, brewery waste and cheese whey (RFA, 2006a). The cost of production of fuel ethanol from corn in USA in 2006 was estimated in the 0.33-0.50 Euro/l range against 0.21-0.29 Euro/l for cost of production from sugarcane in Brazil (Worldwatch Institute, 2006). The energy balance of ethanol production[20] from corn is also much less favourable (1.34, according to Shapouri (1995)) than in Brazil (8.3-10, according to Macedo et al. 2004). In the long-term, the competitiveness of ethanol production from corn will depend on large improvements along all stages of the production chain. (i.e., reducing energy consumption, diversifying energy supply, developing new co-products, improving refinery efficiency, etc.). Anyhow, the perspective are that costs of production can just be reduced 8-15% in mid-term (Worldwatch Institute, 2006).

Table 3. Macro-economic impacts of large-scale biofuels production by 2012

Impact	Expected results
Crude oil imports reduction	by 2 billion barrels/year
Jobs creation	234,840 new jobs in all sectors of US economy
Increase of GDP	by US$ 200 billion between 2005-2012
Increase of farmer's income	by US$ 43 billion just because of raw material purchases (e.g., corn, grain sorghum, soybeans, corn stover and wheat straw)

Source: RFA (2006a)

Despite the strong interests of corn producers, the long-term sustainability of fuel ethanol production in USA will ultimately depend on the use of new feedstocks and, in this sense, there is a strong commitment to develop new routes of liquid fuels production from cellulosic material. However, the EIA (2006) believes that by 2030 more than 93% of the ethanol production should be based on corn and just less than 7% on cellulose feedstocks. This evaluation has been strongly criticised by the Biotechnology Industry Organization –

[20] The ratio of energy contained in the biofuel to the fossil fuel energy used to produce it.

BIO[21] – that "failed to take into account recent developments in the ethanol industry that will ramp up production of ethanol from cellulose (BIO, 2006). In fact, EIA projects a slow growth in production of ethanol from cellulose, reaching less than 4 Gl per year by 2030, when the target under the Renewable Fuels Standard is to reach almost 1 Gl/year in 2013.

3.4 Experiences in Europe and perspectives

The development of biofuels markets in the EU is spearheaded by demand created by policies and measures, rather than by genuine market forces. European Union has a strong policy for promoting the use of alternative fuels and a special interest is put on biofuels. In 2001 a EU Directive established that by 2005 2% of the total transport fuel consumption (energy basis) should be covered by biofuels, while the target for 2010 was set at 5.75%. However, the average biofuel contribution has been minimum (e.g., 0.5, 0.6 and 1% in 2003, 2004 and 2005, respectively) and from 2003 to 2005 10 countries did not use either biodiesel or bioethanol as a substitute. The two countries with higher proportions are Germany (1.21, 1.72 and 3.75%), followed by Sweden (1.32, 2.10 and 2.23% for 2003, 2004 and 2005, respectively) (Rosillo-Calle et al., 2006).

Also, the EU Biofuels Directive has left individual Member States to decide on policies and measures needed to reach the target, as well as biofuels mix strategies most beneficial to each country. This degree of flexibility makes it very difficult to estimate to long term potential penetration of biofuels at EU-wide level; e.g., the Directive stipulates a 5.75% as biofuels in 2010 but on aggregate level without specifying which fuel should be promoted. In its recent Energy Policy Document[22], the EU has adopted a more conservative estimate for 2020 of 10% based on current trends rather than the 20% suggested in previous documents.

Production and use of biodiesel is far more developed in Europe than fuel ethanol. The expansion of biodiesel in the EU has been truly remarkable with production increasing

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[21] According to the own organization, BIO represents more than 1,100 biotechnology companies, academic institutions, state biotechnology centers and related organizations across the United States and 31 other nations (BIO, 2006).

[22] EU Energy Policy published on 10 January 2007.

from 1.93 Mt in 2004 to over 3 Mt in 2005, with an estimated installed capacity in 2006 of 6 Mt. Biodiesel production and used is led by Germany, with an installed capacity of 2.7 Mt in 2006, followed by France with about 0.77 Mt in the same year.

In the EU only a small fraction of ethanol is used as fuel. Total ethanol production (all grades) in the EU is concentrated in some countries (France, Spain, Germany, United Kingdom, Poland and Italy are currently the main producers) and their combined production has covered about 6% of the world production (all grades) in 2005 (2.7 Gl) (Earth Policy Institute, 2006; FO Licht, 2006).

Regarding fuel ethanol, the main players in Europe are Spain, Germany, Sweden and France, that altogether have produced in 2005 84% of the 913 Ml as fuel ethanol (EBIO, 2006). Coincidentally, two of the main European producers – France and Spain –consume gasoline blended with ETBE (8-10%). ETBE has the same effect as MTBE as octane-booster; regarding fuel ethanol, its production is just partially renewable even in case bio-ethanol is used.

The tendency is that more countries would be involved with fuel ethanol production as, for instance, UK, where some plants are under construction. On the other hand, some producers of sugar are planning to convert their facilities to ethanol production after the reform of the sugar regime in EU.

The capacity of fuel ethanol production in Europe by 2005 was estimated as 2.1 Gl, distributed in 13 countries, but with the bulk in Germany (706 Ml in 5 plants), Spain (521 Ml in 3 plants) and France (368 Ml in 4 plants). The additional production capacity predicted to be in operation by mid-2008 is 2.9 Gl, also distributed in 13 countries, but with concentration in France (1.1 Gl, in 5 plants), Belgium (435 Ml in 3 plants) and Germany (238 Ml in 3 plants) (EBIO, 2006).

As indicated, EU Member States have different strategies. The Swedish focus in on fuel ethanol, as 94% of its private car fleet run on gasoline (just 0.6% of the fleet is flex-fuel vehicles; in addition, there are about 400 buses running on ethanol). In Sweden the largest fuelling stations are obliged to sell ethanol and by the end of 2005 about 300 were prepared to do this (Sweden, 2006). In France since 2005 15% of ETBE (from bio-ethanol) and 5% of pure ethanol can be blended to gasoline. The target for 2015 is that on average 10% of biofuels (energy basis) could be added to conventional transportation fuels. French government is offering tax exemption to foster ETBE and ethanol use but in 2005 just 5% of the maximum volume of fuel ethanol were used, while the ETBE consumption reached 85% of its maximum (France, 2006). Spain has also defined its strategy to foster biofuels consumption based on tax exemption as far biofuels are used on blends. Ethanol has been used as ETBE and its participation in 2005 was estimated as 1.5% (energy basis) regarding the total gasoline consumption (Spain, 2006).

The feedstocks used in the EU for ethanol production are sugar beet and wheat. With incorporation of new MS, maize and potatoes could also be used. Lately, surpluses of wine have been converted to fuel ethanol. Feedstock cost is major limiting factor in the EU with prices ranging from US$ 0.74 per litre for wheat to US$ 0.85 litre from sugar beet compared US$ 0.21litre in Brazil (USDA, 2006). The short- to mid-term perspectives are that production costs can just be reduced 15-20% (Worldwatch Institute 2006).

In fact, ethanol production from food crops (e.g., maize and cereals) is far from competitive when compared to gasoline and diesel prices and it is not likely this will change even on the longer term (Faaij, 2006). Additionally, most of the results available indicate that the energy balance of ethanol production from wheat or sugar beet is around 2 (Worldwatch Institute 2006), which does little to reduce GHG emissions.

Aware of the constraints of fuel ethanol production from the current available technologies and feedstocks, EU is putting a large effort on the development of the so-called second generation of biofuels, based on cellulosic materials. It is believed that using residues or biomass that can be produced at relatively low cost, EU domestic production of biofuels could be competitive in mid to long-term. The conversion of ligno-cellulosic material to ethanol has received particular attention in Sweden and to a lesser extent in UK, Spain and the Netherlands. In addition, other routes based on biomass gasification for syngas production and subsequent conversion to biofuels (i.e., methanol, dimethylether (DME), Fisher-Tropsch liquids or even hydrogen) are also intensively investigated in many of the EU MS (Faaij, 2006).

In the short-run the tendency is avoiding any strategy of large-scale implementation of biofuels until feedstock costs can be reduced significantly. Moreover, a strong driver of pro-biofuel policies has been the defence of the interests of European farmers. For instance, the main biofuel producers in Europe – Germany and France – have both political and cultural interests in their agricultural sectors, explaining the high support levels for local productions of biodiesel and ethanol (Faaij, 2006).

3.5 Perspectives in Japan

Japan is one the main consumers of motor gasoline in the world (see section 4) and is heavily dependent on imported oil. The country has considered large-scale use of fuel ethanol, or ETBE, targeting at improving its energy security and at reducing GHG emissions, in this case in order to accomplish its Kyoto obligations. Since 2005 the use of E3 is not mandatory in Japan and by now ethanol blends are used in some regions. Japanese government intends to define a mandate for E3 valid for the whole country and to expand this mandate to E10 by 2010. However, there is some resistance due to the low number of large-scale ethanol suppliers and also due to the interests of oil companies that prefer gasoline blends with ETBE rather than with fuel ethanol (Piacente, 2006).

During 2006 it was announced by the Environment Ministry that a new policy would require all new cars to be able to run on a blend of 10 percent ethanol by 2006. The same Ministry has set the goal to have all cars in Japan capable of running on the new fuel by 2030; most probably, these vehicles will be flex-fuel models (Ethanol News, 2006).

Japan is a producer of synthetic ethanol but has no conditions to produce ethanol from biomass in a large extent. In fact, in 2005 Japan has been the second largest importer of ethanol (more than 500 Ml; see section 5) that has been mostly used as fuel ethanol.

In case a mandate for fuel ethanol blends is decided, or even in case of ETBE blends, Japan will certainly be one of the main markets for fuel ethanol in the world.

3.6 Other countries: experiences and perspectives

Mainly due to concerns regarding current and future constraints on oil supply (security and high costs), countries like China, India, and some Southeast Asian nations are rapidly expanding their biofuels production and use (RFA, 2006a).

China is currently the third larger producer of fuel ethanol in the world and is obviously the focus of attention due to its high economic growth rates in recent years. In 2005 the capacity of ethanol production (all grades) was estimated as 3.8 Gl (DSD, 2005) while the fuel ethanol consumption reached about 1 Gl (Martinot, 2006). There are four state-designated fuel ethanol enterprises in China summing-up a production capacity of 1.3 Gl/year, although other plants are operating and contributing to the ethanol supply (DSD, 2005). Recently China has constructed the largest ethanol production plant from corn in the world. Liu (2006) reports the construction of three new plants summing-up a capacity equal to 1.5 Gl/year of fuel ethanol production.

In China, more than 80 percent of ethanol is made from grains including corn, cassava, rice etc. About 10% is made from sugar, 6% from paper pulp waste residues, and the rest from ethylene by synthetic process (Liu, 2006).

Government plans are that fuel ethanol production shall grow up to 2.5 Gl in 2010 and up to 12.6 Gl in 2020 (Martinot, 2006). This fuel ethanol capacity would cover part of the total consumption if E10 is going to be used all over the country.

So far Chinese government has made mandatory the use of E10 in nine provinces (at central and northern China) that account for about one-sixth of that country's vehicles. Officials say that this mandate aims at reducing the oil demand – that is currently 40% imported – and also aims at improving air quality in big cities. However, Chinese authorities also frequently highlight the targets of helping stabilize grain prices and raising farmer's income[23].

Due to limited land resources and to low crop yields (e.g., in many regions of China soils have serious potassium deficiencies) Chinese government is making an effort at diversifying feedstocks and technologies of ethanol production. The aim is to produce fuel ethanol from sweet sorghum, sugarcane and cassava, besides corn, and to develop technology for ethanol production from cellulosic material. In this sense a pilot-plant with capacity of producing 750 kl/year through acid and enzymatic hydrolysis of sawdust and rice straw is in operation in Shanghai and another plant with capacity of 3.8 Ml/year of fuel

[23] For instance, see People's Daily online at http://english.peopledaily.com.cn/

ethanol production from the stalks of sweet sorghum has been built in Helongjiang (Zhenhong, 2006).

Thus, a general conclusion is that considering the importance of the grain supply issue, China will develop fuel ethanol step-by-step, and will prioritise the development of ethanol production from non-food related crops (Liu, 2006).

India is also a focus of attention regarding its future energy demand. The country has long tradition as sugarcane producer – has almost as much land producing sugarcane as Brazil – and is one the main ethanol producers in the world (see Table 2). However, India has historically directed a large percentage of its crop to sugar production, as its domestic market is huge and heavily regulated. On the other hand, traditionally most of the Indian ethanol production is directed to the industrial consumption (Rosillo-Calle and Walter, 2006).

Recently, mainly due to economic and strategic reasons, Indian government has seriously considered fuel ethanol production and a mandate for E10 blends is currently effective in 13 states. Up to 2010 the mandate for E10 shall be effective in the whole country. In addition, the Indian Institute of Petroleum had conducted experiments using a 10-percent ethanol blend in gasoline and 15-percent ethanol in biodiesel (DSD, 2005).

India has potential to be a large-scale fuel ethanol producer from sugarcane and its dependency on foreign oil supply justifies such priority. However, contrary of Brazil land availability shall be a matter of concern in India and can effectively constrained fuel ethanol production. In addition, also contrary to the Brazilian case, sugarcane is produced by many small farmers (about 7 million) and cost reductions due to scale of production will be more difficult.

Thailand imports 90% of its oil consumption and spend with these purchases about 13% of country's GDP. In this context, Thai government pursued a policy of enlarging the domestic production and the consumption of biodiesel and fuel ethanol. Fuel ethanol should displace MTBE and the consumption by end of 2006 was estimated as 340 Ml (DSD, 2005).

Large-scale production of fuel ethanol production has started with molasses but cassava was officially designated the prime raw material. Thailand is a large producer of cassava and, depending on rainfall, it is possible to grow even three crops per year. In addition, land of low fertility can be utilized even with minimal inputs of fertilizers. As the domestic price of sugar is too high it doesn't worth to produce ethanol from sugarcane.

According to the Thai government policy, by the end of 2009 there will be at least 24 ethanol plants in operation, totalling a production capacity of 1.7 Gl. Production capacity shall reach 1.8 Gl by the end of 2011 (FO Licht, 2006).

By early 2006 the demand for fuel ethanol has already increased but domestic production was able to cover only 30% of the total demand. The construction of some plants have been delayed and because of the tight supply situation oil companies started to press the Thai government. In Thailand all premium gasoline shall be replaced by E10.

The same goal of premium gasoline displacement by E10 has been considered by Philippines. The government intends to establish up to 10 ethanol plants, totalling a production capacity of about 360 Ml by the end of 2008. However, sales of gasohol have been negligible during 2006 (FO Licht, 2006). The production in Philippines will be based on sugarcane.

4. Future Ethanol Markets

It is a recurrent question what share of the world's supply of transportation fuels can be provided by biofuels. Factors to affect biofuels demand include the demand of liquid fuels in itself (i.e., the demand for the transportation energy service), the feasibility of biofuels production regarding oil derivatives (i.e., oil prices, cost of biomass, further cost of technologies of biofuels production), improvements of conventional vehicles regarding energy efficiency, the importance of strategic and environmental issues and the stage of other unconventional or less-conventional transportation technologies (e.g., hybrids, fuel cell).

In the future a much more diversified fuel mix must be observed in the transportation sector (Gielen and Unander, 2005) but for about two decades substantial changes shall not be observed. According to a prospective study by IEA (2003), by 2025 it should become clear what technologies and fuels are likely to dominate the transport market and, at that point it will be possible to realize if a totally new infrastructure will need to be created. Though, for many years the importance of liquid fuels shall continue that would be used in modernized spark-ignition and diesel engines, and also in hybrid vehicles.

A forecast exercise was developed in order to quantify the possible share of fuel ethanol market regarding the energy demand of the transportation sector and how important shall be fuel ethanol trade. The considered horizon is 2030. In the first part of this section some guiding considerations are presented. In the second part the used procedure and the obtained results are presented and, finally, in the third part it is evaluated the magnitude of fuel ethanol trade.

4.1 Tendencies on motor gasoline consumption

According to a recent report by International Energy Agency (IEA, 2006a) the mismatch between available crude quality, refinery configurations and product demand growth has been an important driving force behind recent high fuel prices. However, investments have been made to build refineries and constraints on supply should ease in the following years. In this sense, one of the forces pushing for fuel ethanol shall be reduced in short-term.

In addition, it is observed a rapid rise in diesel demand, especially in Europe, with a corresponding decline in gasoline consumption. Advances on the performance of diesel engines – that are intrinsically more efficient than spark-ignition ones – have encouraged the purchase of diesel-fuelled passenger vehicles. In Europe, lower taxes on diesel have fostered this tendency and the diesel-fleet shall rise from 30% in 2005 to almost 43% in 2011. As consequence, gasoline demand is expected to decline by 17.4-23.2 Gl in the 2006-2011 period (IEA, 2006a).

On the other hand, in the United States, the largest market of motor gasoline in the world, the short-term forecast in that the demand will continue to rise due to the economic growth with reflects on purchases of more powerful vehicles EIA (2006). Up to 2010, despite improvements in gasoline supply, imports will remain and US shall absorb most of the European surplus.

The opposite is expected for Japan, as the tendency is for shifting toward smaller (under 660 cc) and more efficient vehicles (IEA, 2006c), besides reduction on vehicle sales in itself. Factors that induce these tendencies are high taxes on vehicle's acquisition, ownership and operation, and Japan's aging population (IEA, 2006c). It is expected that gasoline demand should grow by less than 0.5% annually from 2006 to 2011 (IEA, 2006c) while transportation energy use should even drop 0.4% per year on average in the 2003-2030 period EIA (2006).

China is a special case due to its strong economic growth in recent years. The country has become a net importer of oil, the demand for energy has shot up enormously and vehicles purchasing are continuously growing (Rosillo-Calle and Walter, 2006). To reduce the pressure on gasoline demand, Chinese government is taxing larger vehicles at higher levels than smaller ones. The prospects are that Chinese economy will expand by 8-9% in the period 2006-2011 and transport energy demand shall increase by 5-7% (IEA, 2006a). Road transport is the primary factor in China growing demand for transportation fuels (EIA, 2006).

India is also worth to highlight as it is estimated that the demand for road transport fuels should expand by 5.3% over 2006-2011. Although this impressive figure, current India's demand on transportation fuels is just about 40% of China's demand and it's short-term impact on world consumption will be lower (IEA, 2006a).

The estimates of IEA (2006a) are that in the short-run (2006-2011) the transport fuel demand will grow by approximately 2.5% per year, being the rate of growth for gasoline relatively smaller than for diesel. In the long run, the same IEA has estimated that gasoline consumption can reach 2,760 Gl in 2050, according to a baseline scenario, with an average growth rate of 1.84% per year (IEA, 2006c).

In US the general tendency is that in the mid-term individual transportation will be less dependent on gasoline. AIE (2006) estimates that by 2030 about 10% of the total sales of new light-duty vehicles will correspond to flex-fuel vehicles and another 10% will correspond to hybrids. Sales of diesel vehicles will reach 6% of total light-duty vehicle sales. Thus, lower growth rates of motor gasoline consumption in US are expected in mid-term.

In Europe the mid-term tendency is that transportation energy demand will remain fairly flat, with reduction on gasoline consumption and increase on diesel use. It is expected that most European countries will keep taxes on diesel fuel lower than those for gasoline through 2030 EIA (2006).

The long-term perspectives for Japan are that gasoline demand will grow modestly through 2030, approximately following the tendency expected up to 2011. On the other hand, there are many uncertainties regarding the mid-term growth of gasoline demand in other Asian countries. One scenario is that car ownership could exceed that of the United States by 2030, mainly due to the economic growth in China and in other emerging countries. In this case, the average growth rate of gasoline consumption in the 2003-2030 period would be 3.9% per year EIA (2006).

4.2 Estimates on fuel ethanol consumption

4.2.1 Motor gasoline consumption

In order to evaluate fuel ethanol consumption by 2030 a simple forecast model was developed based on historic data of motor gasoline consumption. Gasoline consumption was classified according to the main – current and potential – four consumer countries/regions (USA, EU 25, Japan and China), Brazil and the rest of the World. Brazil is not an important gasoline consumer, but shall be the main fuel ethanol supplier in the years to come. In this sense, it is useful to estimate how large is its potential as an exporter of fuel ethanol. The group "Rest of the World - Brazil" (ROW – BR) is formed by a huge number of countries with very heterogeneous features regarding their importance as gasoline consumer and as fuel ethanol producers. Due to the size of its market in the future it would be convenient to draw special attention to some countries/regions (e.g., India and other emerging countries with potential to be large-scale biofuel producers) in further studies.

In this report motor gasoline consumption data were taken from BP Statistical Review of World Energy (BP, 2006b) and from World Energy Statistics and Balances of International Energy Agency (IEA, 2003; IEA, 2006b). For Brazil, data of motor gasoline consumption were taken from National Energy Balance (Brasil, 2006a). Figure 4 shows the evolution of motor gasoline consumption from 1970 to 2005.

The motor gasoline consumption was evaluated as 1,213 Gl in 2005. USA is the main consumer, capturing 43.5% of the world consumption. As of 2005, China covered 5.2% of the total consumption and Japan 5%. The consumption of the block EU 25 represented 13.5% in 2005 and the group ROW – BR, 31.2%. As mentioned, individually motor gasoline consumption in Brazil is small regarding other countries (1.5%).

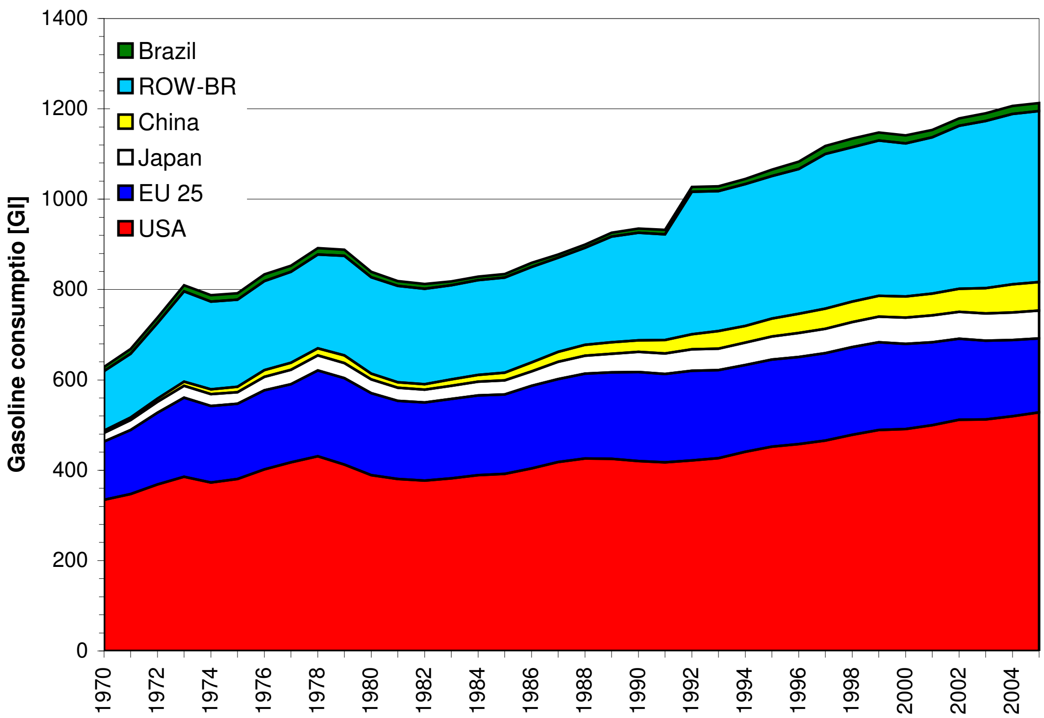

Figure 4. Motor gasoline consumption – 1970-2005

The forecast procedure is based on fitness of equations to the motor gasoline consumption data of recent years for each country/region. When available, estimates of future consumption were added to the series, in order to better capture the expected tendency. Further, the calculated series were again fine-tuned to these estimated values. Information used in this process is presented in Table 4.

Following this procedure, Figure 5 shows the estimated consumption of motor gasoline in USA from 2006 to 2030. The average growth rate during the forecasted period is calculated as 1,39% per year, varying from 1,72% over 2005-2010 to 1,04% in the period 2020-2030 (see Table 5 for comparisons among countries/regions).

Table 4. Information used in the tuning process

Country/Region	Information	Source
USA	Motor gasoline consumption = 675 Gl in 2020[1]	Shell (Ayoub, 2006)
USA	Motor gasoline consumption = 745 Gl in 2030	EIA (2006)
EU 25	Motor gasoline consumption should drop 20 Gl in the 2006-2011 period	IEA (2006a)
EU 25	Motor gasoline consumption = 134 Gl in 2020[1]	Shell (Ayoub, 2006)
Japan	Gasoline consumption must grow just 0.5% per year in the 2006-2011 period	IEA (2006a)
China	Gasoline consumption must grow just 5-7% per year in the 2006-2011 period	IEA (2006a)
Brazil	Fuel ethanol consumption must reach 19 Gl in 2010 and 28.7 Gl in 2015	UNICA (2006)
World	Projected motor gasoline consumption must be close to 2,760 Gl in 2050	IEA (2006c)

Note: [1] the original estimate takes into account the participation of biofuels: 10% in the case of USA and 6% in Europe.

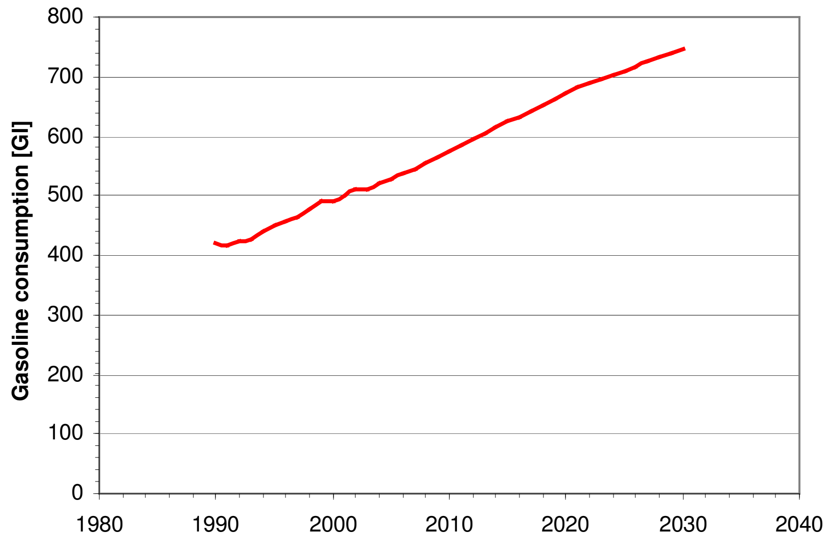

Figure 5. Estimated consumption of motor gasoline in USA – 2006-2030

Figure 6 shows results obtained for EU 25. In the European case, due to the reported switching tendency from gasoline to diesel, the consumption is estimated to drop along the whole period. The average growth rate in the forecasted period is -1,05% per year, varying from -2,82% over 2005-2010 to -0,60% in the period 2020-2030.

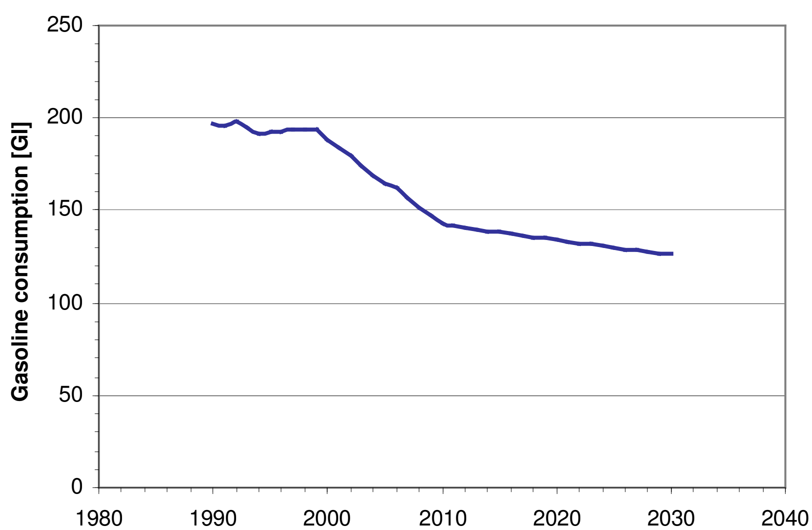

Figure 6. Estimated consumption of motor gasoline in EU-25 – 2006-2030

In the Japanese case, the estimates are that the growth of gasoline consumption should be modest over the period 2005-2030 (0.61% per year, on average), with an even smaller rate from 2005 to 2010 (0,5% per year). Figure 7 shows the estimated evolution of gasoline consumption for Japan.

The opposite is expected to happen in China. Over the period 2005-2010 the growth on gasoline consumption is estimated to be equivalent to 6% per year. As it is very improbable that such a big growth rate can be maintained along the whole period, a slower pace was induced through the procedure. Nonetheless, the annual average rate during the period 2005-2030 would be 4.10%, by far the largest between all analysed countries/regions. Figure 8 shows the estimated gasoline consumption in China in short- to medium-term.

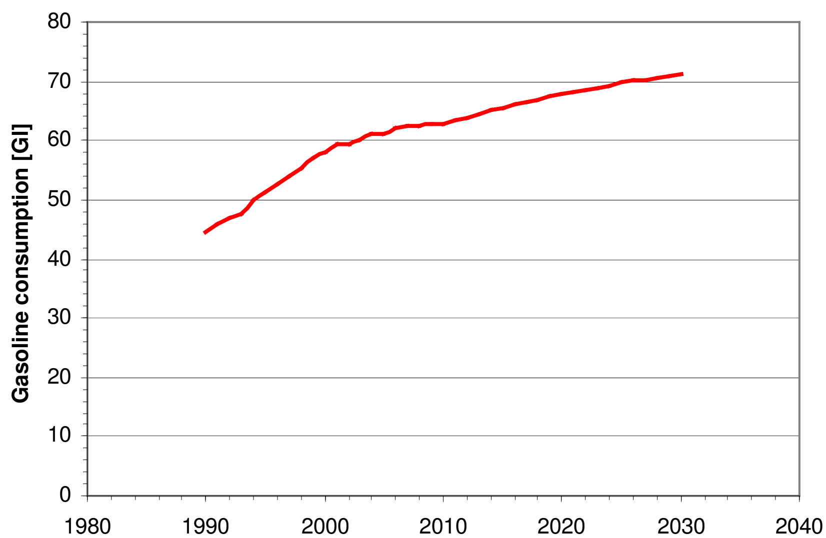

Figure 7. Estimated consumption of motor gasoline in Japan – 2006-2030

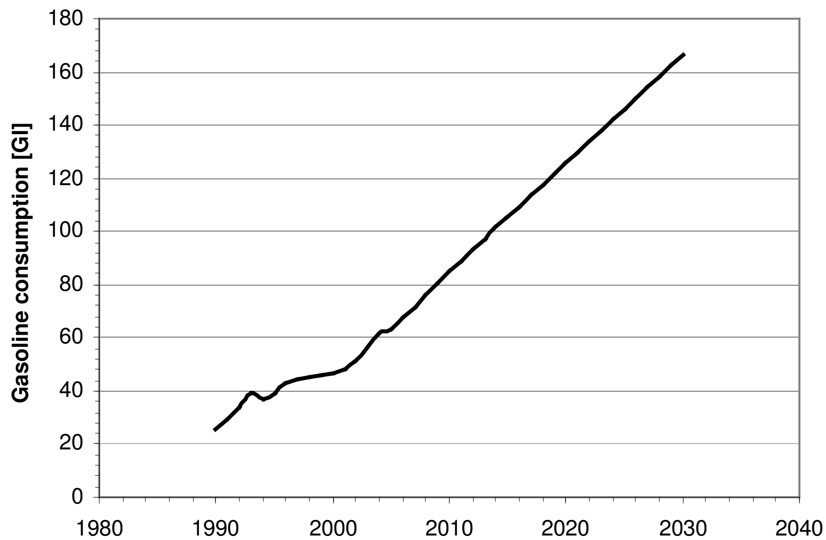

Figure 8. Estimated consumption of motor gasoline in China – 2006-2030

Due to the influence of many emerging countries, it seems plausible that the growth rates of gasoline consumption in the "ROW-BR" region would be in between the estimated results for China and the World. This tendency was obtained for the first forecasted period (2005-2010) and further induced for the rest of the period (2010-2030). The average growth rate in the whole period is estimated as 2.89%, with a slight tendency of reduction along the years. Figure 9 shows the estimated gasoline consumption for the ROW-BR region.

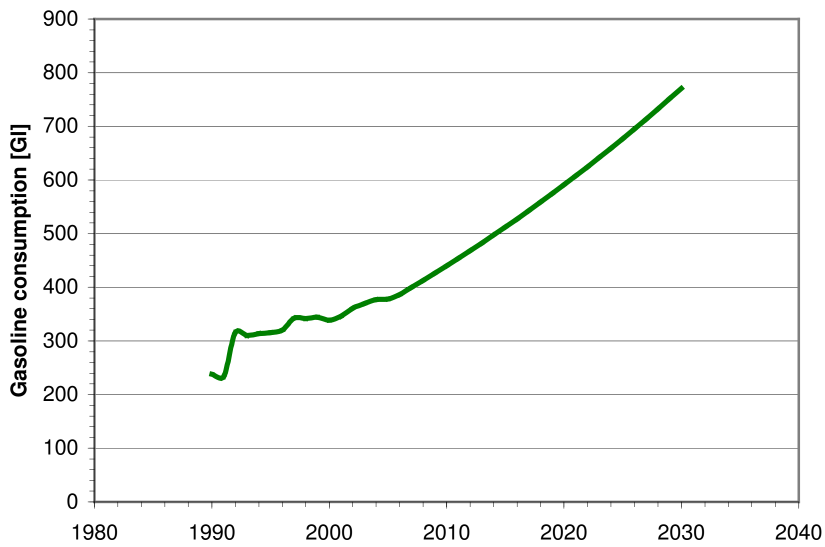

Figure 9. Estimated consumption of motor gasoline in ROW-BR – 2006-2030

Finally, the estimates for the gasoline consumption in Brazil are strongly influenced by the market success of flex-fuel vehicles. The adopted procedure was first to estimate the energy demand for light-duty vehicles and further to deduce from the results the predicted amount of ethanol to be consumed. In this sense, estimates of analysts of the ethanol market were used for the period 2010-2015 (see Table 4). Besides these intermediate figures, the final consumption of fuel ethanol was fitted to the value presented in the National Energy Plan 2030 (50 Gl of fuel ethanol by 2030) (EPE, 2006). An intrinsic hypothesis is that the share of ethanol on energy transportation demand will grow up to almost 55% (ethanol/total fuel demand, volume basis) in 2020 and then tend to stabilize due to the competition ethanol-gasoline.

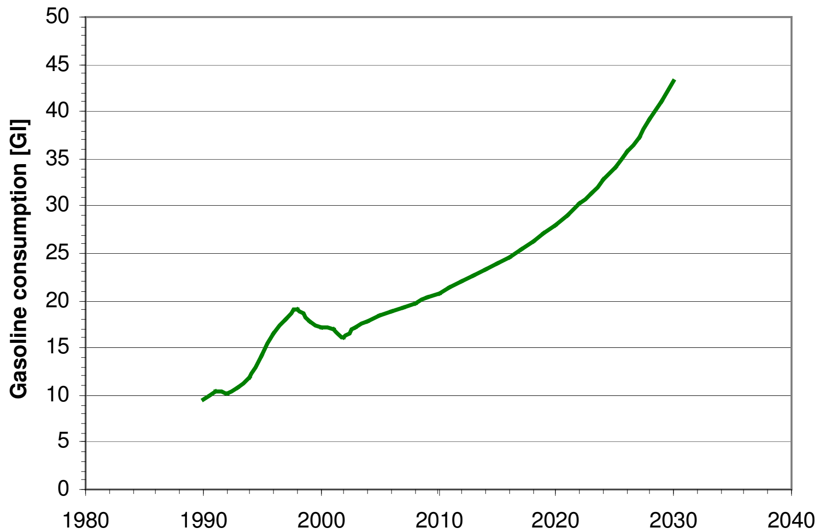

Figure 10. Estimated consumption of motor gasoline in Brazil – 2006-2030

Figure 11 shows the estimated evolution of motor gasoline consumption in the period 2005-2030. On the other hand, Table 5 summarises the estimated results of motor gasoline consumption in 2030. A comparison between the results and corresponding figures gathered in the literature is also presented. General sense, results are accurate regarding all figures of comparison, being the only important difference the estimated tendency of slightly growth of gasoline consumption in Japan regarding a scenario presented by EIA (2006) in which gasoline consumption can even drop in the 2003-2030 period. Results indicate that along 25 years the bulk of gasoline consumption will displace from the most developed countries (USA, Japan, EU 25) to developing nations. Consequently, in mid-term developing countries could have an important role as producers and also as consumers.

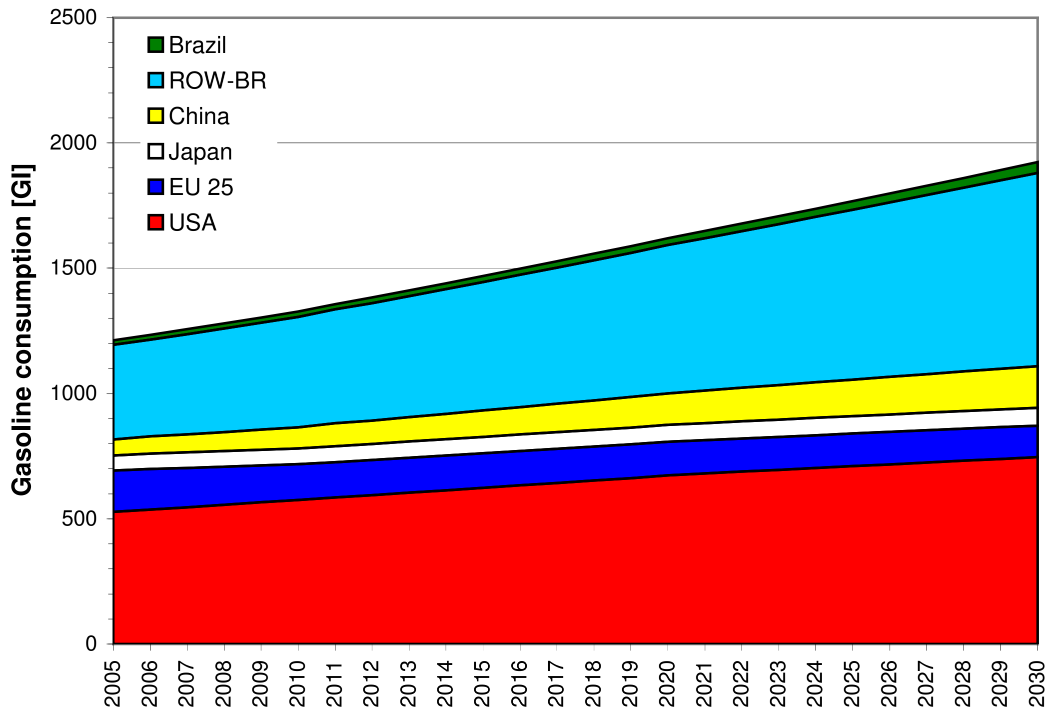

Figure 11. Estimated evolution of motor gasoline consumption – 2006-2030

Table 5. Motor gasoline consumption in the world – data for 2005 and estimates for 2030

Country/region	Growth rates (%)		Growth rates (%)		Consumption (Gl) in 2005	Consumption (Gl) in 2030
	2006-2011	2006-2011	2003-2030	2003-2030		
	Estimated	Reference	Estimated	Reference		
USA	1.75		1.40		528 (43.5%)	746 (38.8%)
EU-25	-2.71		-1.19		164 (13.5%)	126 (6.6%)
Japan	0.50	0.50	0.63	-0.40	61 (5.0%)	71 (3.7%)
China	6.00	5-7.0[1]	4.10	3.90[2]	53 (5.2%)	166 (8.7%)
ROW-BR	3.26		2.76		378 (31.2%)	771 (40.0%)
Brazil	2.62		3.50	3.50[3]	18 (1.5%)	43 (2.2%)
World	1.91		1,80	1.84[1a]	1,213	1,924

Sources: [1] IEA (2006c), [2] EIA (2006), [3] EPE (2006)

Note: [a] growth rates over 2003-2050.

4.2.2 Fuel ethanol consumption

In a short to mid-term fuel ethanol consumption will be induced by mandates in all countries, except in Brazil due to the fleet of FFVs that is growing very fast[24]. The estimates or targets of fuel ethanol use, previously presented (see section 3), are summarized in Table 6. In case of USA, two targets are considered regarding 2030, 55.3 and 227 Gl; these two alternatives define the Scenarios 1 and 2, respectively. Based on these targets/estimates, and also on the estimates of motor gasoline consumption presented above, fuel ethanol consumption was estimated over 2006-2030.

Table 6. Targets/estimates on fuel ethanol consumption

Country/region	Value/when	Equivalent to	Comment
USA	27 Gl by 2012	E4.6	≈95% (hypothesis) of the target of 28.4 Gl of biofuels defined by the Energy Policy Act
	55.3 Gl by 2030	E7.4	Estimated by US DOE (EIA, 2006)
	227 Gl by 2030	E30	Foust (2006); possible mandate by 2030
EU 25	2.5% by 2010	E3.6	Hypothesis assumed by the authors
	17.5% by 2020	E14.4	EU target defined in January 2007
	20.0% by 2030	E28.5	Hypothesis assumed by the authors
Japan	E10 2015 onwards		Hypothesis assumed by the authors
China	2.5 Gl by 2010	E3	Production targets on fuel ethanol
	12.6 Gl by 2020	E10	Production targets on fuel ethanol
	E10 by 2020		Target defined by the Chinese government
ROW-BR	E1 by 2010, E10 by 2020		Hypothesis assumed by the authors

Evaluating fuel ethanol consumption depends on the hypothesis of relative efficiency between vehicles fuelled with E0 and those fuelled with any gasoline-ethanol blend. Simplifying the procedure, it was assumed that until 2010 and as long as fuel ethanol use is not higher than E5, fuel efficiency would be 1% lower than an E0 vehicle (i.e., relative

[24] Currently less than 10% of the Brazilian fleet of passenger cars – estimated as 22 million vehicles – have flex-fuel engines. However, many manufacturers only make cars fitted with flex-fuel engines (FO Licht, 2006).

efficiency = 99%). Until 2020 and for fuel ethanol use higher than E3, fuel use efficiency would be equal than an E0 vehicle. Finally, after 2020, if fuel ethanol use is equal or even higher than E10, fuel efficiency use is 1% higher than an E0 vehicle.

The ratio between the relative efficiency and the volume of ethanol required to displace a given volume of motor gasoline was taken from IEA (2004). The far right point in each of the two lines shown in Figure 12 corresponds to estimates done on the performance of Brazilian vehicles hypothetically running on E5 and E10[25]. As can be seen in Figure 12, running with E5 and in case of relative efficiency 99%, 8.6 litres of fuel ethanol would be required to displace 5 litres of gasoline; running with E10 and in case of relative efficiency 100%, 13 litres of fuel ethanol would be required to displace 10 litres of gasoline.

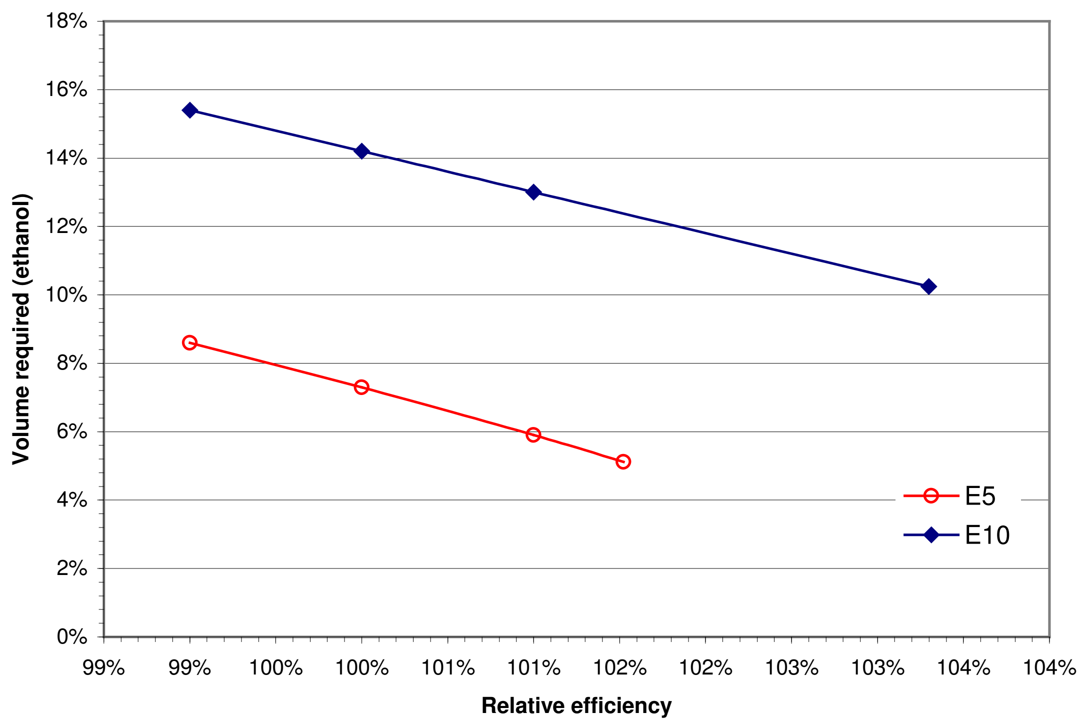

Figure 12. Volume of ethanol required as function of the relative efficiency regarding E0

[25] According to Joseph Jr., typical specific consumption (volume basis) of Brazilian vehicles running on E22 would be 5.5% higher than a similar E0 model. In case of an E100 model, specific consumption would be 29.4% higher.

For the Scenario 1, the estimated ethanol consumption from 2006 to 2030 is shown in Figure 13. In this case the consumption of fuel ethanol would reach 272 Gl in 2030 (from 33 Gl in 2005), allowing the displacement of 10% of the calculated demand of motor gasoline (displacement of 191 Gl vis-à-vis estimated consumption of 1,924 Gl) (see Figure 14).

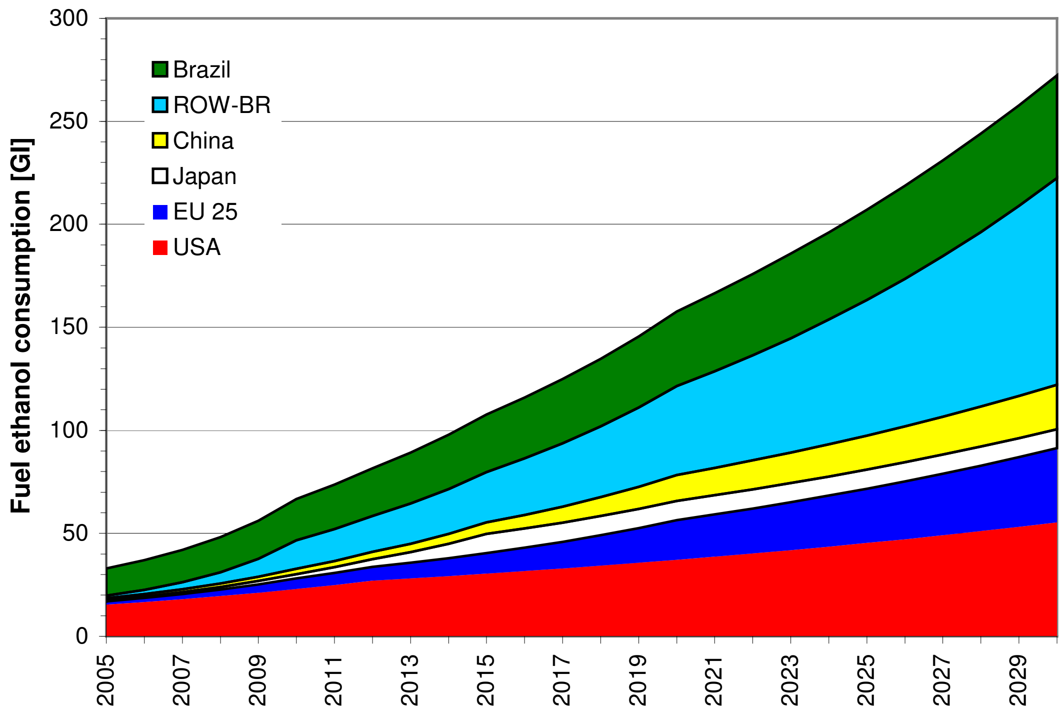

Figure 13. Estimated consumption of fuel ethanol over 2006-2030 – Scenario 1

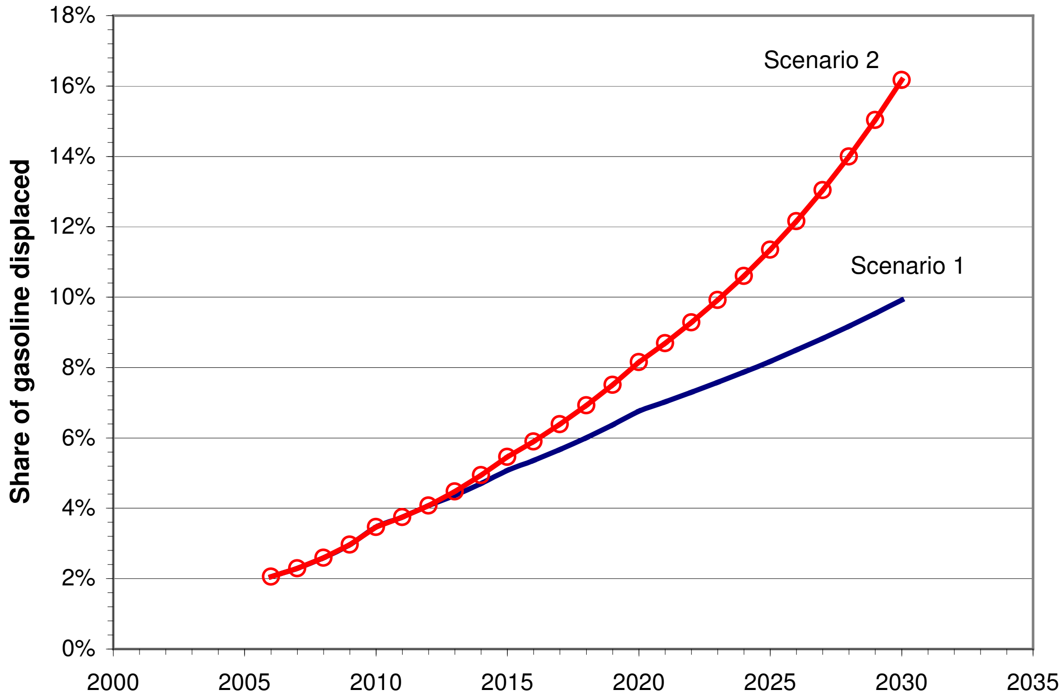

Figure 14. Share of motor gasoline that would be displaced due to fuel ethanol use

Table 7 presents a comparison between consumptions and annual growth rates for the different countries/regions. For Scenario 1, the hypothesis that the fuel ethanol consumption will be equivalent to E10 in many parts of the world by 2030 (Japan, China and ROW-BR) and more than E10 in EU 25 leads to a dramatic growth on consumption, specially in the ROW-BR region. In the ROW-BR case the estimated annual growth rates of consumption are very large, mainly in very short-term, and even the hypothesis that fuel ethanol consumption would be equivalent to E1 by 2010 barely will be accomplished.

In case of EU 25, the hypothesis that fuel ethanol would represent 20% of the consumption of gasoline (energy basis) by 2030 implies that the share of fuel ethanol would reach 28.5% by volume. This consumption level can only be reached with a reasonable share of the Otto cycle fleet especially adapted (e.g., flex-fuel vehicles).

Table 7. Fuel ethanol consumption in the world – 2005 and 2030

Country/region	Consumption (Gl) in 2005	Consumption (Gl) in 2030	Annual growth rates 2005-2010	Annual growth rates 2005-2030
USA[1] – Scenario 1	15.3 (46.4%)	55.3 (20.3%)	8.4%	5.3%
USA – Scenario 2	15.3 (46.4%)	227 (51.1%)	8.4%	11.4%
EU-25[2]	1.6 (4.9%)	36.0 (13.2%)	26.0%	13.2%
Japan[3]	0.5 (1.5%)	9.3 (3.4%)	34.3%	12.5%
China[4]	1.0 (3.0%)	21.6 (7.9%)	20.4%	13.1%
ROW-BR[5]	1.3 (3.9%)	100.2 (36.8%)	60.8%	19.0%
Brazil[6]	13.3 (40.3%)	50.0 (18.3%)	8.6%	5.4%
World – Scenario 1	33.0	444.1	8.6%	11.0%
World – Scenario 2	33.0	272.4	15.1%	8.8%

Notes: [1] RFA (2006a) for the consumption in 2005.
[2] Consumption in 2005 estimated as the domestic production of about 900 Ml (EBIO, 2006) plus the imports of 700 Ml (FO Licht, 2006).
[3] Consumption in 2005 estimated equivalent to the net volume of imported undenatured ethanol (FO Licht, 2006)
[4] Based on Martinot (2006).
[5] Consumption in 2005 calculated per difference, considering the world fuel ethanol consumption equal to 33 Gl (hypothesis previously explained).
[6] Brasil (2006a)

In case of Brazil, estimates of fuel ethanol consumption possibly correspond to its maximum over 2020-2030. It seems very improbable that in a competitive market (induced by a large fleet of FFVs) fuel ethanol consumption could be higher than 55-60% vis-à-vis the total fuel consumption (volume basis). On the other hand, in comparison with other countries/regions, fuel ethanol consumption by 2030 (55.3 Gl) seems to be modest in a context in which all other countries will have fuel ethanol consumption at least equivalent to E10.

Figure 15 shows the estimated fuel ethanol consumption from 2006 to 2030 in case of Scenario 2. In this case the consumption would reach 444 Gl in 2030, being 51% of the world consumption concentrated in USA (227 Gl). The difference between Scenarios 1 and 2 is the fuel ethanol consumption in USA after 2012; the assumed hypothesis in case of Scenario 2 is a geometric growth on consumption, from 27 Gl (2012) to 227 Gl (2030). In this case, about 16% of the calculated demand of motor gasoline would be displaced (311 Gl) by 2030 (see Figure 13).

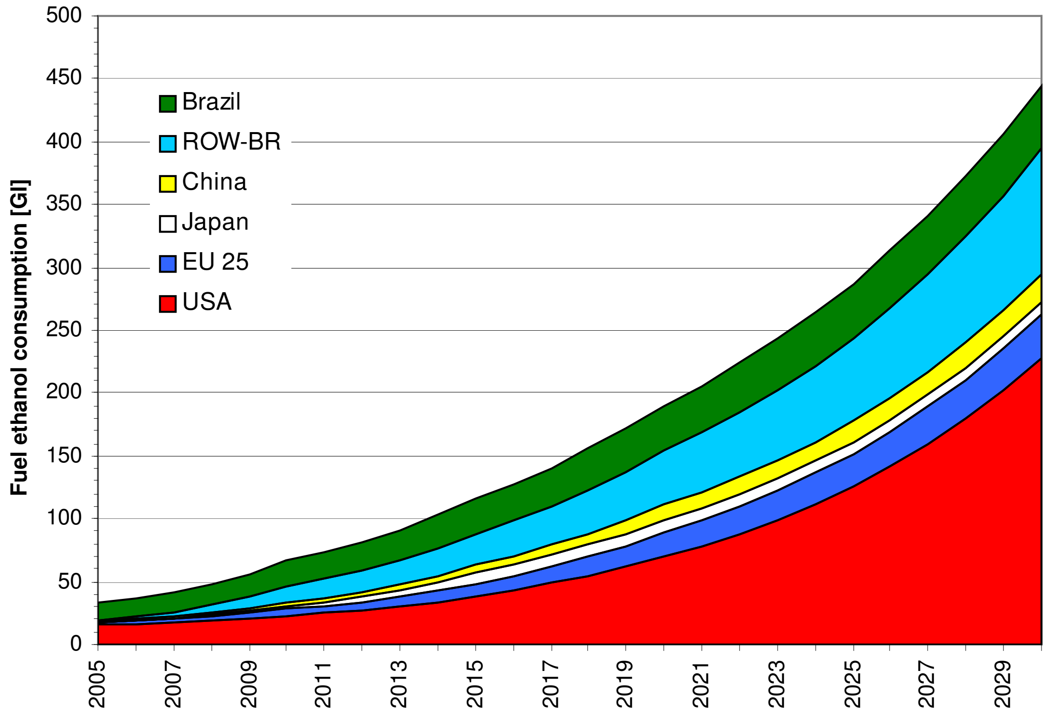

Figure 15. Estimated consumption of fuel ethanol over 2006-2030 – Scenario 2

4.3 Evaluating fuel ethanol production and trade

Besides obvious issues such as land availability and weather adequacy, the extent of fuel ethanol production in a specific country will depend on the relevance of difference factors, including protective policies to local farmers (mainly in the case of USA and EU), the issue of dependency on energy supply, concerns regarding food supply, predicted future costs of fuel ethanol production and how committed a given country will be regarding GHG emission reductions.

General sense, a "high trade" scenario would be defined by a context in which issues as reduction of GHG emissions and moderate costs of energy supply would receive high priority. Some countries/regions could potentially produce reasonable amounts of fuel ethanol but at high costs and using technologies/feedstocks that don't bring substantial advantage regarding GHG emissions. Opposite, the context of a "low trade" scenario would be defined by priorities such as lower dependency on energy supply and preservation of the status-quo of local farmers.

In order to define the magnitude of fuel ethanol trade in short- to mid-term an exploratory exercise was developed. Such a problem has a large number of variables and it is impossible, with the information available so far, to be accurate on results.

The basis of the adopted procedure is the following. Firstly, the capacity available in 2005 for fuel ethanol production was evaluated. Next, the capacity of production through conventional technologies and feedstocks was evaluated from Berg (2005) and complementary sources. Berg presents an estimate of the capacity of fuel ethanol production through 2020, divided according to the main producing countries. In case of China, the estimates were complemented with information about the plans of Chinese government for the years 2010 and 2020[26] (Liu, 2006; Martinot, 2006). In case of Brazil, the estimates were checked with forecasts of the Brazilian government (Brasil, 2006b). In case of Japan, it was assumed that the country is unable to produce ethanol from biomass in large-scale. Subsequently, a single projection was done for each region/country in order to estimate production capacities after year 2020. The estimates of fuel ethanol production through conventional technologies and feedstocks for 2005-2030 are presented in Table 8.

Then, a complementary step was taken to verify whether it is possible or not to reach the estimated capacities of production (e.g., land availability can be a constraint). Results presented by (Fulton, 2004) were used for this purpose. The study considers that up to 2020 only commercial technologies of ethanol production would be available (from sugarcane, grain, beet, etc.) and after that year some plants of ethanol production from cellulosic material will come gradually on-line. The study takes into account constraints on land

[26] The information reflects the necessary production and not the capacity of production. As consequence, as is further presented, the balance supply/demand tends to match in these years.

availability (also considering the production of biodiesel), yields features (evolution pattern and caps) and a ramp-up scenario of the installed capacity[27].

Table 8. Estimates of fuel ethanol production (conventional technologies) – 2005-2030 [Gl]

Region/country	2005	2010	2020	2030
USA[1]	16.2	26.0	45.2	64.2
EU-25[2]	2.1	10.5	22.1	43.9
China[3]	1.3	2.5[6]	12.6[6]	18,2
ROW-BR[4]	1.0	2.5	6.4	10.3
Brazil[5]	18.0	26.0	44.7	62.0
World	38.6	67.5	131.0	182.0

Notes: [1] RFA (2006b).
[2] EBIO (2006)
[3] DSD (2005)
[4] Assumed by the authors
[5] Brasil (2006)
[6] Liu (2006)

Table 9 presents the estimated limits of fuel ethanol production for the main regions/countries according to the Fulton's study. In case of USA and EU, the maximum capacity of ethanol production using traditional technologies and feedstocks are, respectively, 68.2 Gl and 27.3 Gl; once achieved, in both cases in 2020, it will not be possible to enlarge the production. The maximum capacity presented by 2010 for Brazil (21 Gl) is lower than the capacity that the Brazilian stakeholders assure will be on-line in the same year (25-26 Gl) and, thus, 21 Gl was not considered a constraint.

[27] Two scenarios were developed regarding biofuel production. The first just considers ethanol production from sugarcane, as it is currently the biofuel of lowest cost. The second is an extension of the sugarcane scenario, considering biofuels from various feedstocks. As the second scenario is wider, its results were here taken into account. In the Fulton's study a particular “maximum ramp-up” pathway from 2005 through 2050 was considered. Regarding sugarcane, for most of the countries cane production was restricted to a maximum of 10% of cropland area. Brazil was analysed without this constraint, as much more land is available there. Combined yields (l/ha) were assumed to grow 0.9%/year in Brazil and 1.4%/year in other countries (departing from lower yields). Regarding ethanol production from other feedstocks, up to 10% of the cropland could be used in case of US and EU, being 5% the limit considered for the rest of the world. It was assumed that combined yields for the production of ethanol from grains and sugar beet can grow, on average, at 0.8%/year.

Table 9. Limits on fuel ethanol production – 2010-2030 [Gl]

Region/country	Comments	2010	2020	2030
USA	Ethanol produced from corn	28.9	68.2	68.2
EU-25	Production from grain + beet	12.1	27.3	27.3
China	Ethanol produced from sugarcane	1.9	7.6	16.0
ROW-BR	From different feedstocks	22.4	96.1	171.9
Brazil	Ethanol produced from sugarcane	21.0	61.3	121.2
World		86.3	260.5	404.6

Source: Fulton (2004)

Comparing data presented in Tables 8 and 9 it can be seen that the estimated production in EU-25 by 2030 (43.9 Gl; Table 8) is well above the maximum possible production from conventional technologies (27.3 Gl; Table 9). Thus, 27.3 Gl is the limit to be considered once this production is achieved.

In case of China, Fulton (2004) has estimated just the capacity of production from sugarcane; here it was assumed that the difference between data presented in Table 8 and 9 could be potentially produced from other feedstocks.

The estimated capacity of production in mid-term from conventional technologies and feedstocks is shown in Figure 16. The world capacity would reach 182 Gl in 2030, from 38 Gl in 2005.

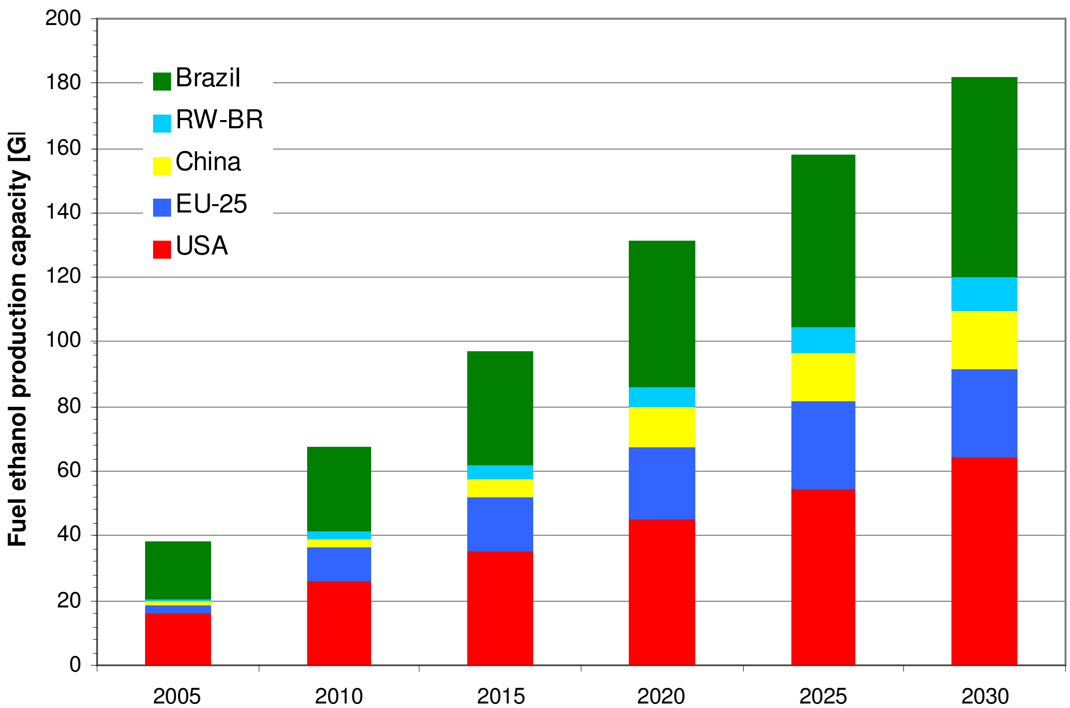

Figure 16. Estimated fuel ethanol capacity of production (conventional technologies)

It is worth noticing that over 2020-2030 the estimated capacity of production would be close to its maximum (according Fulton, 2004) in USA, EU-25 and China. Thus, without significant imports this tight situation could result in risky shortage and high costs of supply. In Brazil, in the other hand, by 2030 the production capacity would be just about 50% of its cap according to Fulton (2004). In case of ROW-BR the adopted procedure leads to a very low capacity of production (10.3 Gl) in 2030 regarding its estimated potential capacity (almost 172 Gl, being 161 Gl from sugarcane). In fact, the potential of ethanol production in the region ROW-BR is significant and should be focus of further studies[28].

The comparison between the estimated consumption of fuel ethanol over the period 2005-2030 (see section 4.2) and the estimated capacity of production (see Figure 16) allows the evaluation of deficits/surpluses in each region/country. Figure 17 shows the results

[28] Regarding 2030, Fulton's (2004) report indicates a large potential capacity for ethanol production from sugarcane in India (49.7 Gl) and a large capacity dispersed in Latin America, except Brazil (42.7 Gl), Africa (35.6 Gl) and Asia, except China (31.2 Gl).

considering the predicted ethanol consumption regarding Scenario 1. The region ROW-BR is further discussed in more details.

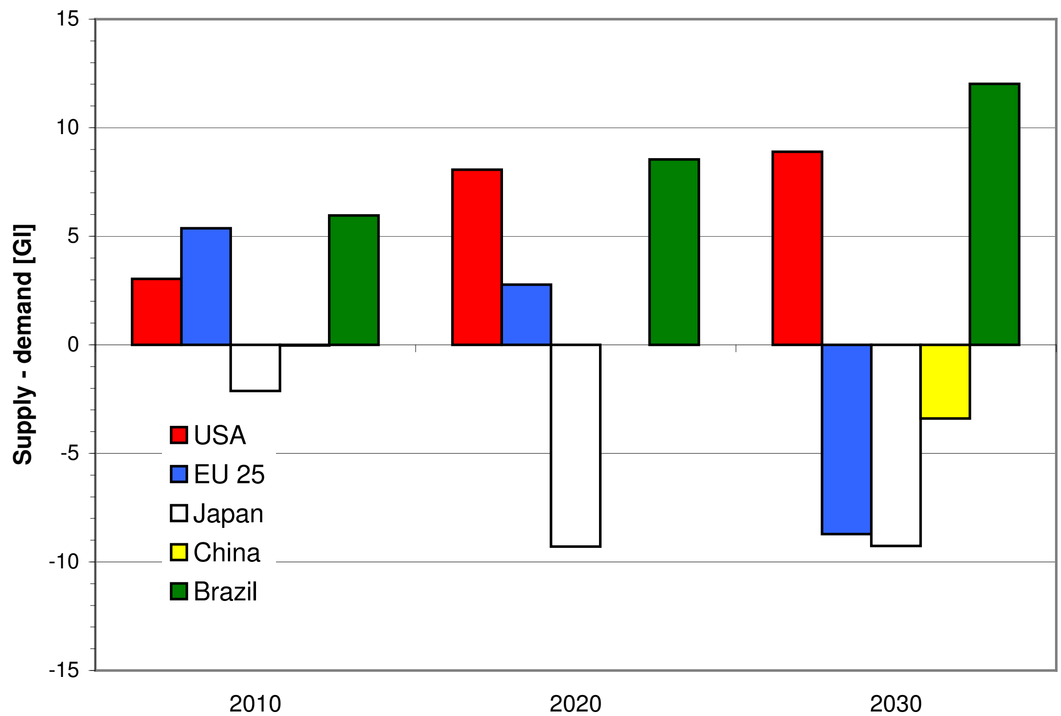

Figure 17. Estimated balance between potential supply and demand of fuel ethanol – Scenario 1 for USA [Gl]

In short-term (2010) the balance is basically null for China, negative for Japan (2.1 Gl, that would have to be imported), but positive for USA, EU-25 and Brazil. In 2020 the balance in EU-25 is still positive (2.8 Gl) but negative in 2030 (8.7 Gl to be imported), even considering the maximum possible production of ethanol from grains and sugar beet. In China the balance is still null in 2020, but negative in 2030 (3.4 Gl to be imported). Japan would have to import about 9.3 Gl in 2030 in order to match the demand.

In case of USA the balance would be positive all over the period, reaching 8-9 Gl over 2020-2030 (according to the capacity of production presented in Table 9). Conversely, another evaluation indicates that ethanol production from corn can just reach 51.5 Gl by 2030 (EIA, 2006) and, thus, in this case it would be necessary to import at least 3.8 Gl to match the demand at that year. This evaluation derives from a study by USDA (US Department of Agriculture) and DOE aiming at evaluate the potential of biomass production in USA, in a sustainable basis and without impacting food, feed and fiber uses (Perlack et al., 2005). Thus, even considering a modest target of displacing just 7.4% of the estimated consumption of gasoline by 2030, USA would have to significantly import in case large-scale ethanol production from cellulose were not a feasible option at that time.

The results also show that Brazil can be an exporter all over the period, able to at least export 12 Gl by 2030. However, taking into account the cap presented by Fulton (2004), the potential for exports in 2030 would be 71.2 Gl (121.2 – 50), i.e., Brazil could cover by itself the combined deficit of EU-25, Japan, China and eventually USA (25.2 Gl). In 2006 the average combined yield in Brazil was estimated as 5,609 l/ha (UNICA, 2006); supposing a growth rate of 0.9%/year (IEA, 2004) for the combined yields from 2007 to 2030, the production of 75.2 Gl (50 + 25.2) would require 10.8 Mha (3.1 were used for ethanol production in 2006 (UNICA, 2006)). Brazil has about 90 Mha to be used for agricultural purposes, without displacing food production and jeopardizing areas that must be preserved (Embrapa, 2004). Thus, for instance, the production of 100 Gl (50 Gl for domestic consumption and 50 Gl for exports) would require 14.4 Mha, being 11.3 Mha additional.

In the case of ROW-BR, large deficits on fuel ethanol supply can be observed in Figure 18, ranging from 8 Gl in 2010 to 80 Gl in 2030. However, as previously mentioned, the potential for ethanol production in this region is very high; e.g., India alone could produce from sugarcane about 6 Gl in 2010 and 50 Gl in 2030 (IEA, 2004). Figure 11 shows the comparison between the calculated deficits in this paper with the potential estimated by Fulton (2004) for ethanol production from sugarcane. Depending on the year, the development of 45-55% of the potential of fuel ethanol production in sugarcane producer countries, excluding Brazil, would be required to match the estimated demand.

In conclusion, in case large-scale production of ethanol from cellulose were not feasible in 20-25 years, the only way to assure that fuel ethanol could displace 10% of the gasoline consumption is through trade. Even in case USA, EU 25 and China maximize their domestic production, about 20% of the estimated consumption of fuel ethanol by 2030 in these countries, plus Japan, would be covered by imports.

The strategy to go for the cap regarding domestic production just makes sense if security of energy supply is the maximum priority for a given country. On the contrary, this strategy would result a very expensive supply, could produce a very modest impact regarding reduction of GHG emissions and, most probably, could cause adverse impacts on food supply as ethanol production in USA and EU-25 is based on corn and grains[29]. Thus, a larger trade would be imperative.

Hypothetically considering that USA, EU 25 and China explore just 70% of its maximum capacity of ethanol production (values presented in Table 9 for USA and EU 25, and 18.2 Gl for China (see Table 8)), these countries would have a deficit of 45.2 Gl regarding the estimated consumption by 2030, i.e., 37.2% of the consumption should be covered by imports. As mentioned, Brazil and other potential producer countries of fuel ethanol from sugarcane could supply this volume.

The intrinsic hypothesis of Scenario 2 – i.e., consumption of 227 Gl of fuel ethanol in USA by 2030 – is that the country would prioritise the issue of security of energy supply, reducing its dependence on imported oil through large-scale domestic production of fuel ethanol from cellulosic feedstocks[30]. It is estimated that by 2030 USA could produce 51.5 Gl from corn and 178 Gl of ethanol from cellulose (Perlack et al., 2005). In this case, US imports of fuel ethanol would be reduced to a minimum.

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[29] Due to the large increase of ethanol production from corn on USA in early 2007 it has been noticed that high elevation of prices of corn and even supply shortages have occurred in Mexico.

[30] "Fuels derived from cellulosic biomass can dramatically impact national (US) economic growth, national energy security, and environmental goals" (DOE, 2006).

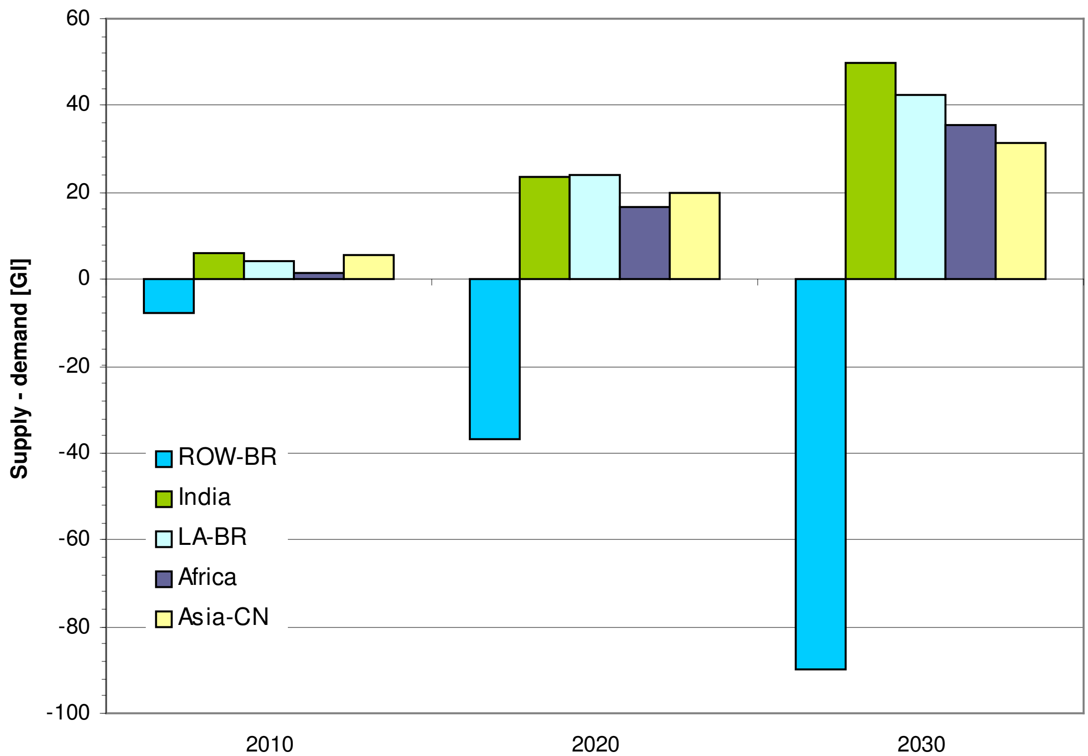


Figure 18. Estimated balance between potential supply and demand of fuel ethanol [Gl] – ROW-BR

Additionally, whether USA is able to produce such a large amount of ethanol from cellulose, European countries, China and even Japan (e.g., from imported feedstocks or from residues) wood produce as well. The impact on ethanol trade is difficult to predict, but a possible scenario is that trade flows would be mostly constrained among developing countries and due to trade agreements between developed countries and developing ones (e.g., in order to induce economic development in low developed countries).

Ethanol production from cellulose is not a commercial route so far and the prospects are that it can reach a commercial stage by 2015-2020, or even further. The road map presented by US DOE in 2006 (DOE, 2006) defines a research phase to be completed in 5 years-time, a technology deployment phase within 10 years and a system integration phase for 15 years; thus large scale production would be possible later than 2020. The current available technology, which is based on dilute acid hydrolysis, has about 35% efficiency (biomass to ethanol; HHV basis) and technological improvements can bring the ethanol efficiency to 48%[31]. A combined effect of improvements on efficiency, learning-effects, increase of scale and reduction of biomass costs (about 30-35%) could induce 60% reduction on production costs in 20 or more years (Hamelinck et al., 2005). Even though, it is estimated that cellulosic ethanol may be competitive with ethanol production from corn, grain and sugar beets, but not with the production from sugarcane: it is estimated that the mid to long-term costs of cellulosic ethanol would be in the 22-55 Euro/m^3 range, in comparison with the predicted 18-26 Euro/m^3 range for ethanol costs from sugarcane in Brazil (Worldwatch, 2006). In addition, cost effectiveness of reductions of GHG emissions is also uncertain due to the doubts regarding the energy balances of cellulosic ethanol production.

Large-scale ethanol production from cellulose seems to be the only way to make fuel ethanol use a feasible option to displace more than 10-15% of the world gasoline consumption by 2030. Regarding trade perspectives, the risk is that the largest markets for fuel ethanol – USA and Europe – would prioritise the issue of the independence of the energy supply and constrained trade in short- to id-term in order to preserve its markets for the second generation of fuel ethanol.

Considering the estimated figures on oil dependence in 2005, presented in Table 10, and supposing that the target for each country/region is to accept a dependency on fuel ethanol supply, by 2030, no larger than about 50% of the current dependency on oil, trade flows of fuel ethanol would reach 91.5 Gl. As can be seen in Table 10 USA would be the only country where large-scale ethanol production from cellulose would be compulsory in order to match the predicted demand in 2030.

It is clear from the results presented that USA and EU will have a central role on future fuel ethanol trade. The priorities of its energy and environment policies can constrain or deploy ethanol production in developing countries. Without clear possibilities of trade, investments on building or enlarging the capacity of production of fuel ethanol will not occur. For the majority of the countries with good potential to produce ethanol their domestic markets are

[31] Mostly in biomass pre-treatment and advances in biotechnology, especially through process combinations (Hamelinck et al. 2005).

very small in comparison with potential trade volumes. Without specific investments for exports, surplus amounts of ethanol will just allow trade on the margin.

Table 10. Estimated trade of fuel ethanol by 2030 – Scenario 2 of fuel ethanol consumption

Country/ region	Ethanol consumption – 2030, Scenario 2 [Gl]	Dependence on energy supply [%]		Fuel ethanol trade [Gl]	Domestic production[2] [Gl]	
		Oil in 2005	Ethanol 2030		Conventional	Cellulose
USA	227.0	65	30	68.1	68.2	90.7
Europe	36.0	80	40	14.4	27.3	0
Japan	9.3	97	50	4.7	0	4.6
China	21.6	40	20	4.3	18.2	0

Source and note: [1] based on BP (2006b), considering diary oil consumption and oil imports; in case of Europe, it was considered the figures for Europe and Eurasia, excluding the data of former URSS. [2] Conventional domestic production corresponds to the potential previously presented; domestic production corresponds to the difference.

5. Fuel ethanol trade

World Bank studies predict that free trade – in general, not specific to biofuels – could lift tens of million people out of poverty (Gresser, 2006). From radical trade liberalization the global gains were estimated at nearly $300 billion a year (Gordon, 2006). Traditional trade theory argues that economies gain from trade by specialising in products where they have a comparative advantage (The Economist, 2006). Thus, those who produce at lower costs and with higher quality should have advantages on trade. In practice, this is not what occurs because countries use to impose trade barriers in order to protect local production. This practice is common for most goods and is particularly more frequent regarding agricultural products.

Trade barriers include import duties higher than the practice for most goods – in general, in case of agricultural goods, much higher rates – and a set of other mechanisms that include, quotas, high internal subsidies, technical specifications and sanitary rules.

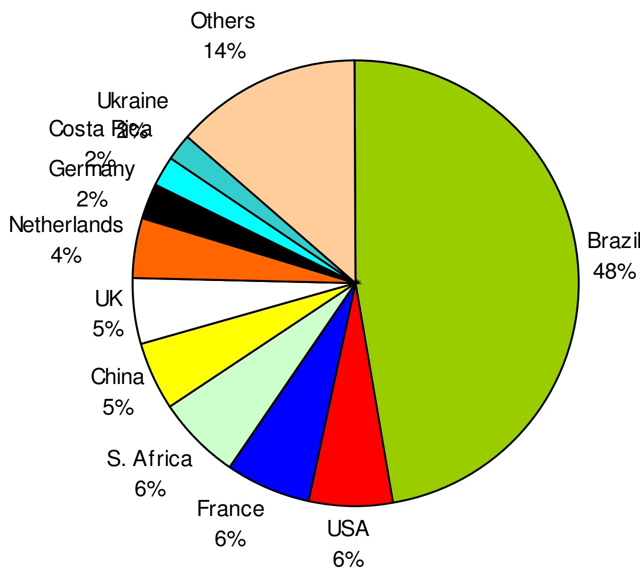
In the previous section it was shown that many countries/regions are not able to match their own demand in case fuel ethanol is used in a large-extent. In fact, even large-scale producers of fuel ethanol need to ensure conditions for a well-structured international trade market. Fuel ethanol trade is essential because of: (i) the need to have strategic alternative sources of supply in case of domestic market problems; (ii) the possibility to form planned stocks; (iii) the contribution to domestic price balance when production costs are high; (iv) to induce the reduction of subsidies; and (v) the possibility of implementing fuel ethanol use in non-producing countries (Carvalho, 2004). However, fuel ethanol is still in its infancy and there are many barriers to be overcome. Unless changed, these barriers will retard development of bioenergy in countries with comparative advantages and encourage the development of the biofuels production where it is more expensive (Hazel and Pachauri, 2006).

5.1 Recent trade flows

Data about fuel ethanol trade are imprecise due to various potential uses of ethanol (fuel, industrial or for beverage use) and also because of the lack of proper codes for biofuels in the Harmonized System Commodity Description and Coding System (HS) (UNCTAD, 2006). Estimates on ethanol trade (all grades) provided by FO Licth (2006) indicate that trade has almost steadily grown from about 3 Gl in 2000 to 6 Gl in 2005 (i.e., about 13% of the world production, estimated as 45 Gl). Over the 1995-2002 period ethanol trade has varied between 2.8 and 3.8 Gl; supposing that the rise in recent years was mostly due to fuel ethanol trade, it is reasonable to estimate that in 2005 trade has covered about 10% of the fuel ethanol consumption.

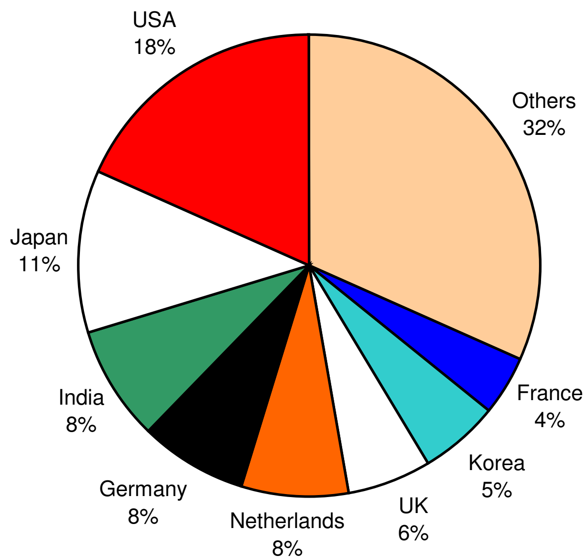
Fuel ethanol is traded under HS code 2207, which covers denatured and undenatured alcohol. Both can be used as fuel ethanol, but denatured ethanol is often used as solvent (UNCTAD, 2006). In this case a material is added to ethanol to make it undrinkable and removed it is expensive (Rosillo-Calle and Walter, 2006). From the 6 Gl of ethanol traded in 2005, 4.7 Gl (almost 80%) corresponded to undenatured ethanol with at least 80 degrees strength (FO Light, 2006). Trade of denatured ethanol, which corresponded to 20% of the traded volume in 2005, remained basically unchanged during the 2000-2004 period (UNCTAD, 2006).

Based on FO Licht (2006) data it is possible to identify the origin of 5.5 Gl exported in 2005 and the destination of 4.5 Gl imported (roughly 92% and 75% of the volume traded, respectively). Figure 19 shows the main exports (a) and the main imports (b) of ethanol in 2005.



Source: FO Licht (2006)

Figure 19 (a). Main ethanol exporters (all grades) in 2005



Source: FO Licht (2006)

Figure 19 (b). Main ethanol importers (all grades) in 2005

As expected, there are less exporter countries than importer ones and in recent years Brazil has been by far the main exporter. Among the countries that have been both exporters and importers, just USA, the Netherlands and Germany were net importers in 2005.

Almost 97% of the Brazilian exports in 2005 were as undenatured ethanol with high degree strength (FO Licht, 2006); it is estimated that 96% of the total exports were for fuel ethanol (UNICA, 2006). In 2005 Brazil exported to 47 countries but the bulk of the trade was with just 12 countries (almost 92% of the total volume). Brazilian exports increased 1.6 Gl from 2003 to 2004, essentially covering all world trade increase at that time. The growth was much lower from 2004 to 2005 (190 Ml) and it seems that many countries have taken advantage of the increase of about 1 Gl on trade, but mainly South Africa[32]. In Table 11 information about the main buyers of Brazilian ethanol in recent years are presented.

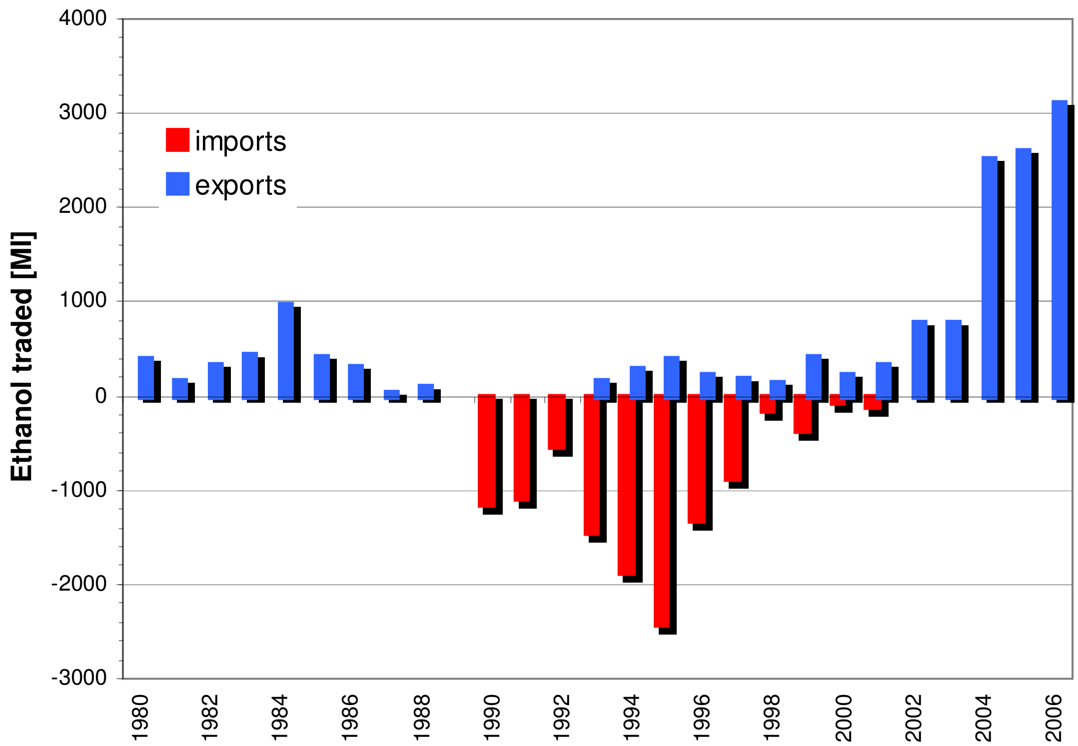
[32] According to United Nations Commodity Trade Statistics Database (COMTRADE, 2006), the exports from South Africa of undenatured ethanol with high degree strength increased 871 Ml from 2004 to 2005.

Table 11. Brazilian exports of ethanol (all grades) in recent years

2005			2004			2003		
Country	[Ml]	US$/m^3	Country	[Ml]	US$/m^3	Country	[Ml]	US$/m^3
India	414.2	278.07	India	478.6	194.24	Jamaica	103.0	167.70
Japan	317.9	292.75	USA	424.6	189.46	Japan	90.4	210.03
Netherlands	264.3	301.01	S Korea	278.4	201.19	Sweden	86.7	210.74
USA	260.6	297.28	Japan	223.2	198.73	Netherlands	84.8	217.12
Sweden	245.1	286.03	Sweden	193.4	238.98	S Korea	55.9	209.36
Total/avg	2,598.5	294.29	Total/avg	2,408.3	206.68	Total/avg	757.0	208.45

Figure 20 presents the evolution of Brazilian exports/imports of fuel ethanol from 1980 to 2006. The value for 2006 (3.1 Gl) corresponds to an estimate (UNICA, 2006). During the 1990s, during a critical period of the Brazilian production, the country has imported substantial volumes of ethanol (mainly from USA and South Africa) in order to reduce supply constraints. It is clear from Figure 19 that even for Brazil – currently the main exporter – large-scale trade of fuel ethanol is a very recent event.

In recent years USA imported fuel ethanol from Central America and Caribbean countries, but traded volumes have been small compared with the US consumption. In 2005 imports of fuel ethanol summed up 424 Ml, being 349 Ml from Jamaica, Costa Rica, El Salvador and Trinidad Tobago (the difference, 75 Ml, from Brazil) (RFA, 2006a). It is interesting to notice that the amount sold to USA is equivalent to 82% of the amount imported from Brazil by these four countries (FO Licht, 2006). In fact, up to 7% of the US ethanol demand may be imported duty-free under the Caribbean Basin Initiative (CBI), even if the production itself occurs in another country (UNCTAD, 2006). For many years a regular flow of wine alcohol from the EU reached the USA through CBI rules (Berg, 2004) and, as consequence, investments were induced in Costa Rica and Jamaica during the 1980s for ethanol dehydration in these countries (Hoekman et al., 2001). El Salvador and Trinidad Tobago also have dehydration plants.



Source: Brasil (2006a)

Figure 20. Brazilian trade flows of fuel ethanol – 1980-2006

5.2 Trade regimes on biofuels

In 2005, the net amount of ethanol imported by USA was estimated as 600 Ml, representing about 5% of their domestic consumption. Also in 2005, net imports to EU 25 were equivalent, representing 19% of its total consumption. These two important markets for fuel ethanol have their own trade regimes, with specific rules.

USA imposes MFN (most-favoured nations) import duties[33] of 142.7 US$/$m^3$ (54 ¢US$/gallon) plus a 2.5% *ad valorem* tariff on ethanol[34]. In many cases this tariff regime

[33] The MFN trade regime does not confer advantages on the receiving nation. Having MFN status means a certain nation will not be treated worse than any other nation. Members of World Trade Organization (WTO) accord MFN status to each other (www.wikipedia.org). MFN tariffs for some commodities are over 100

offsets lower production costs in other countries and impose a significant barrier to imports. The argument is that these tariffs ensure that the benefits of the domestic U.S. ethanol tax credit do not accrue to foreign producers (Elobeid and Tokgoz, 2006). In USA, partial Federal tax exemption of 137.4 US$/m^3 (52 ¢US$/gallon) is applied for ethanol that is derived from renewable resources and used as fuel. Thus, the additional tax on imports aims at offset the domestic Federal tax exemption to foreign production. (US International Trade Commission, 2004).

An example presented in a report of Brazilian Ministry of Foreign Affairs (Brasil, 2006c) illustrates the constraint imposed to countries that are treated under MFN rules. Supposing that the price paid to producers is equal to 370 US$/m^3 of ethanol in USA, the distributor receives 137.4 US$/m^3 as tax exemption and pays just the difference (232.6 US$/m^3). Thus, the cap price (CIF) for a Brazilian producer is 221.8 US$/m^3, that is very close to the average cost of production.

The exemption to the import duties of 142.7 US$/m^3 of ethanol is applied to least-developed countries beneficiary with the GSP (Generalized Systems of Preferences) status, Caribbean and Central America countries (CBI agreement), ATPA (Andean Trade Preference Act) countries, Canada, Israel, and Mexico. In practice, however, there is just a small (far below the 7% cap) but regular flow through CBI countries to USA, as previously mentioned. Investors are building new ethanol plants in Caribbean. During the negotiations of the US-Central America Free Trade Agreement (CAFTA) it was defined specific quotas for El Salvador and Costa Rica within the existing CBI quota (UNCTAD, 2006).

Even with very small impact over domestic production, duty-free treatment of ethanol in USA has raised concerns as some believe that trade expansion from CBI would undermine the local industry. In particular, during 2006 an attempt to get rid to the MFN import duties on ethanol failed because of resistance of Midwest senators (FO Licht, 2006). On the other hand, others believe that trade liberalization would induce modernization of the US industry and could act as safeguard to avoid supply disruptions.

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percent and, in general, such tariff peaks are concentrated in products like sugar, cereals, fish, certain alcoholic beverages, fruits and vegetables, etc. (Hoekman et al., 2001).

[34] An *ad-valorem* tax (i.e., according to valor) is typically imposed at the time of a transaction.

Nevertheless, the numerous state-level subsidies provide so many incentives to the production in USA that significant barriers to imports will remain still even if the import tariffs were to be removed (UNCTAD, 2006).

The US International Trade Commission (2004) recognizes that, in practice, the US ethanol trade policy discourages imports beyond the free-duty quotas already defined in some agreements and almost prohibits imports from countries non-treated with exemption of import duties.

The economic impacts of full ethanol trade liberalization in USA were analysed by Elobeid and Tokgoz (2006). The authors concluded that in USA the consumption should increase by 3.2% (about 500 Ml in 2005), with 7.5% reduction of the domestic production and 14.1% decrease of the domestic prices. Net ethanol imports to USA should increase 192.8% (about 1.2 Gl considering the imports of fuel ethanol in 2005 and 1.8 Gl for the total imports). The authors have also evaluated that, as consequence, the production in Brazil should increase 8.8% (1,4 Gl considering the production in 2005), with 61.9% increase on exports (1.6 Gl regarding 2005) and a 3.2% reduction in the domestic consumption (425 Ml in 2005).

According to the European Commission (FO Licht, 2006), 45% of the ethanol imported by EU in 2005 was as normal MFN regime, 29% under reduced duty regimes and 26% of the imports had no duties. Under MFN regime EU impose a duty of 192 Euro/m^3 on undenatured alcohol (102 Euro/m^3 in case of denatured alcohol). All exports from Brazil to EU are under MFN rules[35]. Reduced duty and duty-free regimes correspond to preferential trade arrangements between EU and developing and less developing countries. Pakistan, for instance, has a quota of 20% of EU ethanol imports and has covered in 2005 about 12% of the total volume traded. Many countries of Africa, South and Central America and Asia are included in these preferential trade arrangements that aims at drug diversion, sustainable development and good governance. Regarding ethanol, EU has much more preferential trade regimes than USA (UNCTAD, 2006).

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[35] In the document An EU Strategy for Biofuels, EC (2006) states that "Brazil is the only country capable of exporting large quantities as MFN".

Förster et al. (2006) state that Europe is not going for a strategy of exclusive domestic production due to two main reasons. Firstly, local production of ethanol is not competitive in the near future (even with the incentive of 46 Euro/ha on set aside land) and secondly, EU wants a beneficial impact on establishing biofuel elsewhere. Indeed, the same authors mention that Europe can not expand its biofuel use creating negative social and ecological impact in developing countries and emerging economies. In this sense, the tendency is that certification of the production will be mandatory in short-term.

The strategy of European Commission for enhancing trade opportunities specifically mentions some of its priorities. Firstly, that the conditions of market access for imported bioethanol will be no less favorable than those provided by the trade agreements currently in force. Secondly, the preferential access will be given to African, Caribbean and Pacific countries. Thirdly, follow an approach aiming at balance the interests of both domestic producers and EU trading partners.[36]

Moreover, other countries, such Australia and Canada, have MFN duties on ethanol imports. Even Brazil, which often claims against the trade duties imposed by USA and EU, imposes a tariff of 60 Euro/m^3 on imported ethanol. Often, Brazilian government threats the producers to get rid to this tariff, but it is still valid.

The barriers regarding biofuels trade are not specifically on the agenda of the trade negotiations sponsored by World Trade Organization (WTO) (Hazell and Pachauri, 2006). As biofuels derive from agricultural feedstocks, the same concerns regarding trade liberalization of agricultural goods are noticed. In particular, ethanol is internationally classified as an agricultural product under HS code 2207 (UNCTAD, 2006).

Before the suspension of the Doha negotiations on July 2006, protective legislation on agricultural products was one of the main issues under discussion[37]. During five years one focus of tension was the continuous demand from developing countries for the cutting farm subsidies mainly applied by USA and EU, while developed nations demanded reciprocal

[36] It seems clear that no special treatment will be given to Brazil in short-term.

[37] The aim of the WTO is to lower trade barriers in the pursuit of expanding global trade. The "Doha Development Round" is a negotiating agenda defined by WTO in 2001 (Gordon, 2006). As no consensus was achieved in the 2006 meeting, most because diversions on how to cut farm subsidies and tariffs, the negoatiations were suspend.

openings in other areas, lowering their barriers to imported goods and services (Gordon, 2006). With the failure of the negotiations over agricultural products, in general, biofuels issue also failed to be solved. In fact, even Brazil, in theory the main loser because of its competitive advantage regarding fuel ethanol production, didn't put emphasizes in this issue as so far ethanol trade is still relatively small regarding other agricultural goods[38].

Another issue under discussion during Doha Round was the liberalization of trade in environmental goods and services (EGS). Most of the negotiations were on how to define "environmental goods" and criteria to identify them. Some countries have agreed with a definition that would include renewable energy products (i.e., fuel ethanol and biodiesel, and related products[39], among others). However, many disagreements have hampered any conclusive result (UNCTAD, 2006). The strategy of classifying biofuels as EGS would make possible to by-pass the most controversial discussion regarding farm subsidies. In addition, once classified as EGS its appeal would be enlarged.

With the fail on Doha Round, opportunities for trade agreements shall be constrained for some time to bilateral deals, such as, in case of Brazil, the EU-Mercosur deal still under discussion.

5.3 Market requirements

5.3.1 Standardization of the final product

One of the constraints for fuel ethanol trade is the lack of a clear and single specification regarding the product, as different countries and some organizations have their own standards. Standardization is crucial both to set the main parameters regarding fuel characteristics (e.g., maximum water content, aldehydes content, flash point, explosion limits, pH, etc.) and to unequivocally define the products that would be treated under

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[38] In 2005 the total income with exports of undenatured ethanol was 766 US$ million (FOB), i.e., 2.5% of the total income with imports of agricultural goods. The income with sugar exports, for instance, was more than five times higher (Brasil, 2006b).

[39] For instance, parts and components of production plants of biofuels, engines and vehicles able to run on biofuels, engineering and consultancy services.

certain trade rules (e.g., there are different duties imposed for denatured and undenatured ethanol in EU, but both products can be used as fuel).

In the USA, specifications of reference are defined by the standard ASTM D 4806[40]. The state of California has additional restrictions in addition to the performance federal requirements. The EU is currently developing an ethanol fuels standard which may be partly based on the standard ASTM D 4806. Until a standard is agreed, individual national standards apply. So far, within the EU, it is seldom mentioned that Sweden has the most advanced standards specification but, in fact, by 2004 Sweden does not have a national standard for fuel ethanol and Sekab (Svensk Etanolkemi AB, a supply of bioethanol) sales specification for anhydrous ethanol 99.5% has served as the industry standard. In Brazil, is Brazilian Oil Agency (ANP) that set standards for fuel ethanol. As an illustration, Table 12 shows the technical specifications of these three standards. It is clear from a single comparison that without a unique standard wide accepted trade can be severely constrained.

Table 12. Some specifications applied to fuel ethanol

Property	ASTM D 4806¹	Sekab²	ANP³
Ethanol volume %, min	92.1	99.8, min	99.3, min
Density, g/ml	not defined	0.79, max	0.7915, max
Methanol, volume %. max	0.5	20 mg/l, max	not defined
Solvent-washed gum, mg/100 ml max	5	not defined	not defined
Water content, volume %, max	4	0.3 weight, max	not defined
Aldehydes (as acetaldehyde), weight %	not defined	0.0025, max	not defined
Denaturant content, volume %, min	1.96	not defined	not defined
Denaturant content, volume %, max	4.76	not defined	not defined
Copper content, mg/kg, max	0.1	not defined	0.07
Inorganic Chloride content, mass ppm (mg/l) max	40	not defined	30
Acidity (as acetic acid), weight %	0.007	0.0025	not defined
pHe	6.5-9.0	not defined	6.0-8.0

Sources: RFA (2002); IFQC (2004); ANP (2006), for anhydrous ethanol

[40] Standard Specification for Denatured Fuel Ethanol for Blending with Gasoline.

In Brazil, an initiative of producers and a government institute aims at defining standard procedures and parameters. The CTC – Sugarcane Technology Centre – and the National Institute of Metrology, Standardization and Industrial Quality – Inmetro – have agreed to work together aiming at develop studies and standards for international classification of fuel ethanol (Estado de São Paulo, 2007). Despite an important initiative, technical specifications and methods of evaluation should be accepted worldwide.

5.3.2. Sustainability and certification

Among the driven forces for fuel ethanol, one of the most important is the growing concern about sustainability. Currently, consumers are yet largely unaware of the issue (Förster et al, 2006), but the tendency is that markets, especially in EU, will claim for certificates and labels in order to – at least – assure the adoption of basic principles and procedures along the whole production chain. In developed markets consumers tend to be more sensitive to environmental and social issues (UNCTAD, 2006).

The large diversity of potential producer countries and the different stages in which these countries are regarding environmental and social laws – and even the differences regarding law enforcement – would induce the consumer market to demand for certification schemes. An important issue, however, it to ensure that certification does not become an obstacle to the international trade (UNCTAD, 2006). It is unacceptable to allow that the certification of production – and even product specification – could become, in practice, a non-trade barrier. In this sense, sustainability criteria should be developed through transparent discussions between consuming and producing countries and criteria shall be as clear as possible. As stated by Förster et al (2006), only if producers in developing countries are involved in the process of defining standards can it be avoided that they can find themselves excluded by the market by new barriers.

Regularly, Non-Governmental Organisations (NGOs) have raised concerns about the potential risk of for fuel crops to be grown on ecological fragile lands, accelerating erosion and the depletion of aquifers, as well as the potential risk of destruction of ecosystems such as rain forests (Hunt, 2006). Some recent initiatives have been developed aiming at develop social and environmental standards for the production of biofuels feedstocks (Förster et al, 2006). Preliminary criteria include conservation of natural ecosystems, preserving genetic diversity, avoiding soil erosion, that priority should be given to food supply, development of jobs in rural areas, participation o local people in decision making, induce social development of the exporting country, etc. (Fritsche et al., 2005).

Regarding trading rules, a controversial issue comes from the fact that products with the same physical characteristics must be equally treated. So, in principle, sustainable feedstock should deserve the same treatment than others, i.e., even synthetic ethanol would be inserted in the same rule. In addition, importing countries must require from foreign products the same compliance they do for they similar domestic product, but it is possible to set life-cycle difference between two “like” products. For instance, ethanol from rain fed sugar cane has different life cycle than ethanol produced from irrigated corn. Thus, it remains debatable the legal aspect of environmental standardization of feedstocks (UNCTAD, 2006).

A special issue concerns the energy balance of biofuels. If biofuels use were going to be deployed in order to contribute to reduction of GHG emissions, in mid-term a product with a favourable environmental impact would be given trade advantages, as specific tax exemptions (Coelho, 2005). The tendency is that at least in mid-term the market should recognize advantages regarding the energy balance and these could reflect on prices, as happened with automotive fuels regarding their specifications.

6. Conclusions

In recent years a rapid growth has been observed regarding fuel ethanol consumption. Consumption has been induced by mandates and it seems clear that the demand will continue to be induced by policies, rather than by genuine market forces. Worldwide, fuel ethanol consumption is currently equivalent to about 2% of the gasoline consumption and it was estimated in this report that in 2030 its consumption could displace 10% of the forecasted gasoline consumption – or even 16%, depending on the policies that USA government is going to implement in the years to come.

This target seems relatively modest but, in fact, a big challenge is associated with. For instance, it will be necessary to enlarge the capacity of production from about 38 Gl of fuel ethanol (estimated as of 2005) to at least 275 Gl in 2030 (or even 450 Gl) – a seven-fold increase in 25 years (or almost 12 fold). Considering that a substantial capacity needs to be built in developing countries (in case of relatively small consumption in USA, it was estimated that more than 60% of the fuel ethanol consumption in 2030 will be concentrated outside developed countries – USA, EU and Japan –, and that the largest potential of production is in developing countries), the challenge is even larger. As stated by Hazell and von Braun (2006) the initial cost of producing and using biofuels are high and a new biofuel industry needs of coordinated investments by farmers, fuel distributors, car manufacturers, etc. The required capacity of production and the necessary structure to make the consumption feasible will require strong cooperation among countries and companies.

Fuel ethanol trade is still in its infancy and there are many barriers to be overcome. On the other hand, from the results presented it is clear that the only way to accomplish the target of displacing 10% of the gasoline demand in 2030 (in case Scenario 1) is by enhancing international ethanol trade. Japan has no conditions to produce bioethanol in large extent and USA, EU 25 and China shall be net-importers of fuel ethanol by 2030, even exploring to the limit their production capacities.

In order to ensure the supply in the years to come, at low cost and without jeopardizing the environment, it is necessary to foster the production in developing countries, to reduce trade barriers and to advance towards a fair definition of sustainability criteria.

On the other hand, the development of the second generation of biofuels can potentially allow some countries to minimize its dependence on imports of biofuels. It is important that developed countries – mainly USA and EU – follow a balanced approach of imports and domestic production. As stated by Förster et al (2006), for a number of developing countries the option to access these markets will determine the dynamics of their own industry.

Biofuels is potentially a win-win solution. Obviously that biofuels will not be the unique solution, but may contribute to solve some of the problems that the world needs to address urgently – e.g., reduction of GHG emissions, improving air quality in large cities of developing countries, reducing dependency on imported oil, creating jobs in rural areas and improving life quality in developing countries. And to enlarge the share of biofuels on future transport energy demand international trade will be crucial.

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Box 1. **Required engine and vehicle modifications due to fuel ethanol use**

It is widely accepted – even by fuels and car manufacturers – that nearly all-recent conventional gasoline vehicles produced for international sale are fully compatible with 10% ethanol blends (E10). These vehicles require no modifications or engine adjustments to run on E10, and operating on it will not violate most manufacturers' warranties (IEA, 2004). On the other hand, there are concerns regarding older models (older than 10-15 years).

For blend levels above E10, some engine modifications may be necessary, though the exact level at which modifications are needed varies with local conditions such as climate, altitude and driver performance criteria (EAIP, 2001). In Brazil, cars with electronic fuel injection (including imported cars with minor modifications) have operated satisfactorily on a 20% to 25% ethanol blend since 1994. There have been few reported complaints about drivability or corrosion (Moreira, 2003).

Ethanol has a lower calorific value (22.4 MJ/l for anhydrous ethanol vis-à-vis about 32-33 MJ/l for gasoline) and has oxygen in its composition, characteristics that require a different set-up on fuel injection system and a different air-fuel ratio for combustion. In addition, ethanol is more aggressive to metals (corrosion), rubber and plastics (chemical attack), requiring changes on materials specifications. Ethanol also has lower vapour pressure regarding gasoline that impacts engine start-up at lower ambient temperatures.

Up to 10% ethanol use in the fuel blend the only required modification – and just for old vehicles, with no fuel injection system – is on the carburetor. Besides the new set-up due to the lower calorific content, its materials should be changed or protected (e.g., aluminium and polyamide).

For up to E20-E25 the required modifications are much deeper, but it is not necessary to change or convert the engine in itself (DSD, 2005). All vehicle devices that are in contact with fuel should be modified and/or protected, including electronic fuel injection system (e.g., use of stainless steel, substitution of the fuel injector, calibration of the air-fuel ratio, set-up of the lambda sensor working range), fuel pump (e.g., protection of internal surfaces, changes on materials and connectors sealing), fuel filter (e.g., also protection of internal surfaces) and fuel tank (e.g., protection of internal surfaces and changes on materials, as well). In addition, new calibration of the ignition system is required, evaporative emissions systems should be adjusted and materials of the catalytic converter should be changed.

Obviously that for an E100 engine, as is just the case in Brazil, required modifications on engine and vehicle are even deeper. Some of the devices that require modifications in case of E20-E25 fuel blend should be submitted to additional adjust, as the fuel tank that need to be enlarged in its capacity and the fuel pump that needs to provide higher pressure. In addition, modifications are required on the engine (e.g., higher compression ratio, new surface materials of valves, modifications on camshaft), on the ignition system (e.g., new calibration of advances control, colder heat rating spark plugs), on intake manifold (in order to allow higher air flow and higher intake air temperature), on the cold-start system (e.g., auxiliary gasoline-start system and battery with higher capacity), on the catalytic converter, on exhaust pipe, on lubricant oil and even on suspension (due to the higher vehicle weight).

Box 2. **Policy and regulatory instruments applied in Brazil to support the ethanol market**

Brazilian federal government has taken an important role on deploy the fuel ethanol market in Brazil since 1975. It was relatively easy to address the problem from the producer's side as, indeed, the creation of the ethanol program was also influenced by frequent difficulties faced by sugar cane entrepreneurs due to the excess of sugar production and strong variations of its international prices. The required investment was assured by credit guarantees and low-interest loans and risks were extremely reduced as off-taking guarantees were given both to sugar cane and to ethanol at fixed prices – and prices very attractive, at least at the very beginning. New production units have to be approved by a government commission and, once approved, credit was assured.

Also aiming at assuring the supply, the government has obliged PETROBRAS to provide and operate the required infrastructure of transport, storage, blending and distribution. Eventual deficits of ethanol commercialisation were also assumed by PETROBRAS. At that time PETROBRAS – the Brazilian oil company – was stated-owned.

In parallel, the government has asked a federal research centre (Centro de Tecnologia Aeronáutica) to work on tests and on development of engines, both considering operation with blends and with straight ethanol. The first neat ethanol engine was commercially available in 1979. During the 1980s, the automobile industry at that moment based in the country accepted to give support to consumers and to develop new parts and engines.

In 1975 a mandate for 20% anhydrous ethanol (E20 – volume basis) on fuel blend was imposed. In practice, the share of ethanol on all gasoline commercialised in Brazil reached 20% just by late 1970s. During the supply ethanol crisis in early 1990s its share was reduced to about 10%. In 1993 is has been defined by law that the share of ethanol in fuel blend would be in the 15-25% range, depending on the conditions of ethanol supply. In reality, this range allows that the production can be shifted to more sugar, depending on the sugar international prices, and is very convenient for sugar cane producers.

Also at the demand side, when neat-ethanol cars were launched, in early 1980s, consumers were stimulated to buy them through lower taxes regarding those applied over gasoline vehicles. In addition, due to the control over fuel prices that existed for many years, it was established that ethanol prices to consumers would be close to 65% of the price of gasoline (volume basis). In this sense, consumers identified large advantages on buying neat ethanol vehicles and their sales were a large success until early 1990s. The fleet of neat-ethanol vehicles have reached 4.5-5 million.

The control of ethanol prices was eliminated and the industry was deregulated by 1999. The Brazilian government currently provides support to ethanol production through both market regulations and tax incentives. In terms of market regulations, a blending ratio of anhydrous ethanol with gasoline is imposed, as previously mentioned. For the consumers, a lower excise tax for ethanol than for gasoline is applied with differences along the country (Elobeid and Tokgoz, 2006).

In fact, in Brazil taxes have had a strong impact over the fuel price to consumers. Currently, six different taxes and contributions have been applied over automotive fuels, being just one equivalent to the value-added tax. In 2005 the average taxation over the gasohol in Brazil was estimated as 47%. On the other hand, in São Paulo state, that is the largest producer and consumer of ethanol in Brazil, the taxation over the ethanol was close to 20% in the same year; the average taxation on ethanol in the rest of Brazil was evaluated as 34%. In state of São Paulo the VAT over ethanol is the lowest in the country (about 12%), being an additional advantage the lower value of the annual license paid by owners of ethanol vehicles. Despite lower taxes, in July 2006 the final price of hydrated ethanol to consumers in São Paulo was twice the average price received by producers.

Subsidies applied over ethanol production were completely eliminated with the deregulation process that has finished in late 1990s. However, part of the benefits received by ethanol consumers is due to lower taxes applied over ethanol regarding those paid by gasoline consumers, and for some analysts this a controversial subject. Anyhow, it should be noticed that the taxation applied over diesel is even lower than the correspondent applied over ethanol (about 27% in 2005). Taxes applied over gasoline were higher in the early years of ethanol program and have been reduced since fuels' price deregulation.