Innovations in the production of Bioethanol and their implications for energy and greenhouse gas balances

New production processes, potentials for optimization, international experiences and market developments

Executive Summary

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1 Objectives and content of the study

The EU wants to cut down its overall greenhouse gas emissions relative to the 1990 level by 8% in the period from 2008 to 2012. In addition, within its national climate protection program the German Government has set specific targets for the reduction of CO_2 emissions and of the six greenhouse gases cited in the Kyoto Protocol. The program also aims for a doubling in the proportion of renewable energy sources by 2010 compared to levels in 2000/2001 which can also contribute to the abatement of greenhouse gas emissions.

The transportation sector contributes considerably to the overall emissions of CO_2 and an important share of the rise of CO_2 emissions takes place in this sector.

Therefore, in the light of the commitment of the EU to the Kyoto Protocol, reducing emissions in the transportation sector is an important issue. While several renewable energy sources can be used in stationary applications, the possibilities in the transport sector to use renewable energy sources are very limited. Today, bioethanol and ETBE for gasoline engines and biodiesel (RME) for diesel engines are the only technically mature and marketable renewable fuels.

In March 2003 the European Parliament adopted the “biofuels directive”. Based on energy values, it defines a 2% target for the share of biofuels in overall fuel consumption in 2005 and a 5,75% target for 2010. In Germany biofuels have been exempted from levy duty by amendment of the mineral oil tax law exempted. ETBE from bioethanol is already produced for the German market and direct blending of bioethanol into gasoline has been started as well.

From a climate policy point of view the use of bioethanol as a renewable fuel has been discussed controversial until recently. Critics mainly argue that due to complex conversion processes and limited energy gains greenhouse gas balances are not very favorable. Existing studies on energy and greenhouse gas balances show a wide range of results depending on the assumptions. So far, many studies have not made allowances for recent developments in the optimization of agricultural feedstock production and optimizations as well as innovations in the conversion process. Also credits for by-products often were not taken into account adequately.

Against this background the objective of this study is to generate and evaluate energy and greenhouse gas balances for the production of bioethanol, taking account of new production processes and technologies.

A systematic analysis of a selection of the most relevant and recent studies is the starting point of the study. The main focus is on Europe but for the purpose of comparison studies on the situation in the USA and in Brazil are also included. This overview does not claim to be exhaustive but it presents some general results.

On the basis of the existing literature and data a field study was launched to generate new energy and greenhouse gas balances. The main emphasis of the field study was on the analysis of the effects of new technologies, economies of scale, energetic optimizations, and an improved use of by-products. In addition, different resources for the production of bioethanol were taken into account. Besides the traditional ones the production of bioethanol based on lignocelluloses which is considered as very promising from an ecological and economic point of view worldwide is analyzed.

Selected ethanol producers from Germany, different European countries and Canada were included in the study (see figure 1). Altogether nine current production processes and concepts for the future from seven different producers were analyzed in detail. The different companies and their conversion processes were described and new energy and greenhouse gas balances, based on primary data provided by the companies in a standardized procedure, were generated and interpreted.

New energy and GHG balances for seven companies and nine production processes

Company	Capacity	Feedstock	Pertinence for study
ABENGOA	176.000 m³ (Bioetanol Galicia)	– Cereals – Wine alcohol	European bioethanol market leader
Royal Nedalco	90.000 m³	– Molasses – C-starch	Leading position in the European traditional market. Use of side stream
AGROETANOL	50.000 m³	– Cereals (in particular wheat)	Leading bioethanol producer in Scandinavia. Medium-sized plant, energy supply
KWST	30.000 m³ 60.000 m³	– Molasses – Cereals (all kinds)	Current status quo of ethanol production in Germany; innovative, energy saving process
SÜDZUCKER	90.000 m³	– Sugar beet	Sugar beet as feedstock
IOGEN	220.000 m³	– Wheat straw	Lignocelluloses as feedstock
Agricultural Distillers	9.000 m³	– Cereals (rape seed)	Agricultural small scale plant vs. industrial large scale plants

Figure 1: Selected companies and production processes

An isolated analysis of the production of bioethanol in Europe is not appropriate due to important experiences of other producing countries and due to international trade ties. Brazil is the worldwide leading ethanol producer. Therefore, an analysis of the Brazilian ethanol sector in commercial and ecological terms has been included in the study as well.

Finally, based on the above, the development of supply and demand in the bioethanol sector in Europe is presented which then allows to draw conclusions for the expected dynamics of the European market for bioethanol.

2 Analysis of existing studies

Many older studies on energy and greenhouse gas balances are based on obsolete assumptions and data concerning technologies in agricultural production and in the conversion of agricultural feedstock to bioethanol. Studies from the 1980s and the beginning of the 1990s sometimes even conclude that there is no net energy benefit, i.e. energy inputs during the entire production process of bioethanol are higher than the energy content of the final product bioethanol (see figure 2). Studies from around the turn of the millennium and the prognosis by the IEA already show improved results and considerable net energy savings.

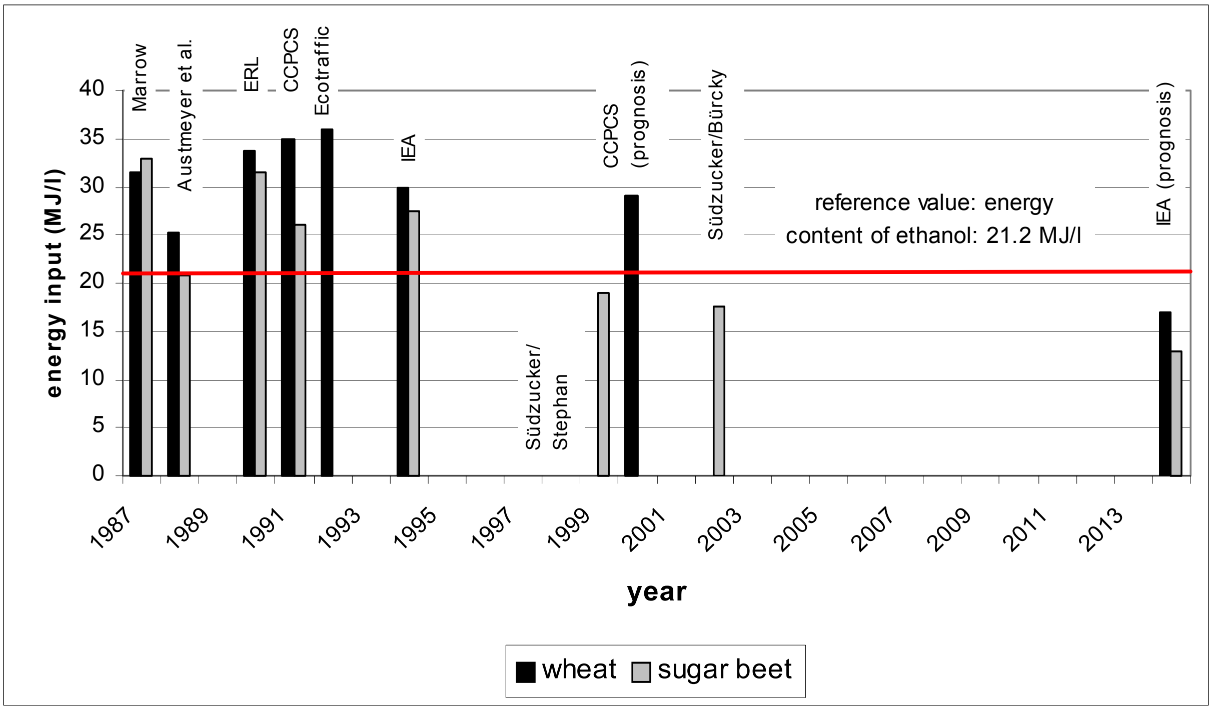

Figure 2: Fossil energy input for the production of bioethanol based on wheat and sugar beet (in MJ/l)

Twelve selected recent studies which were especially relevant for the study at hand were included in the analysis to create an overview of the state of the art of energy and greenhouse gas balances for the production of bioethanol as described in the literature.

These studies confirm the trend of a continuous improvement of energy and greenhouse gas balances. All studies show considerable net energy gains. Most studies come up with energy gains between 8 and 15 MJ/Litre (see figure 3). This also leads to significant savings in the emission of greenhouse gases (see figure 4).

However, the variance of results is quite high. This is mainly due to different approaches in the ecological and economic evaluation of by-products, different processes of agricultural production, the conversion of agricultural feedstock to bioethanol and due to differing system boundaries.

The results of the analyzed existing studies for greenhouse gas balances show a range between 0.5 for the production of bioethanol from wheat and 2.2 kg CO_2-equivalence per litre of bioethanol for the production of bioethanol from sugar cane in Brazil. For bioethanol produced in Germany the best figure is 1.5 kg CO_2-equivalence for the production based on sugar beets. The eminent influence of by-products is reflected in one study for the production of bioethanol from wheat in Germany. Fully accounting for all by-products results in an energy gain of 49.9 MJ/l whereas neglecting all by-products this figure drops to only 6.9 MJ/l (see figure 4).

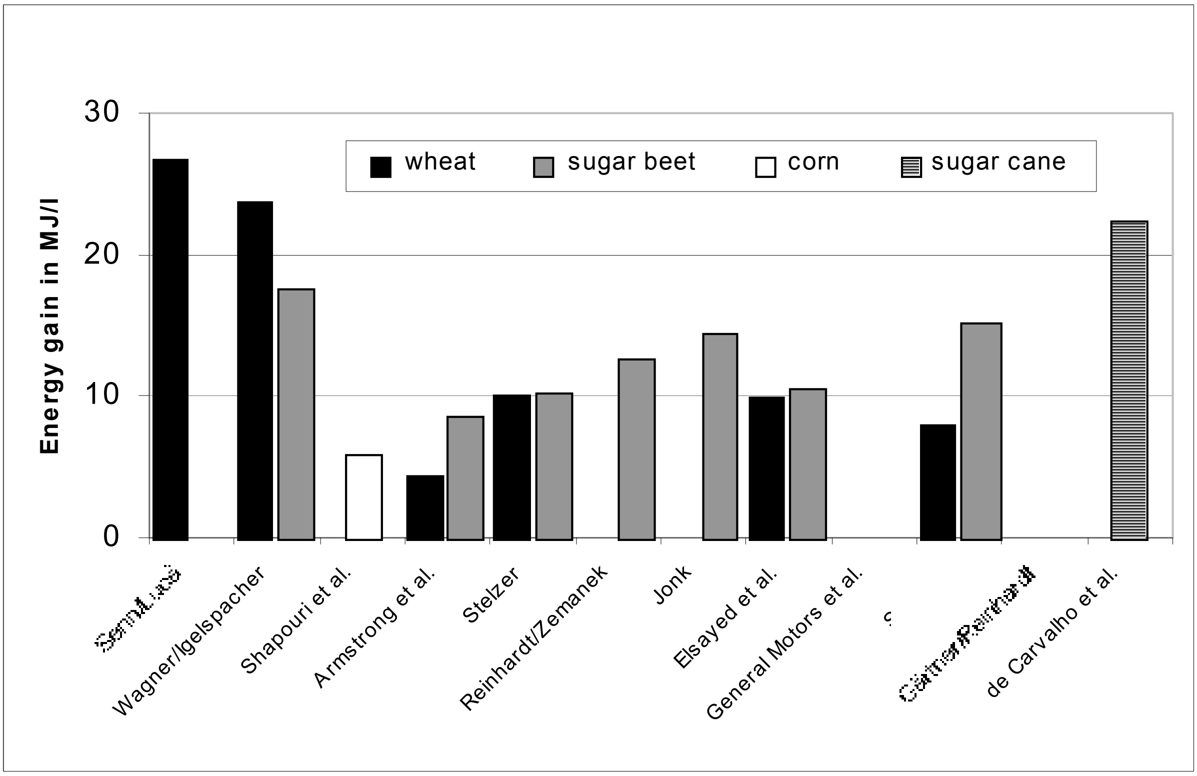

Figure 3: *Energy balance – results from selected studies*

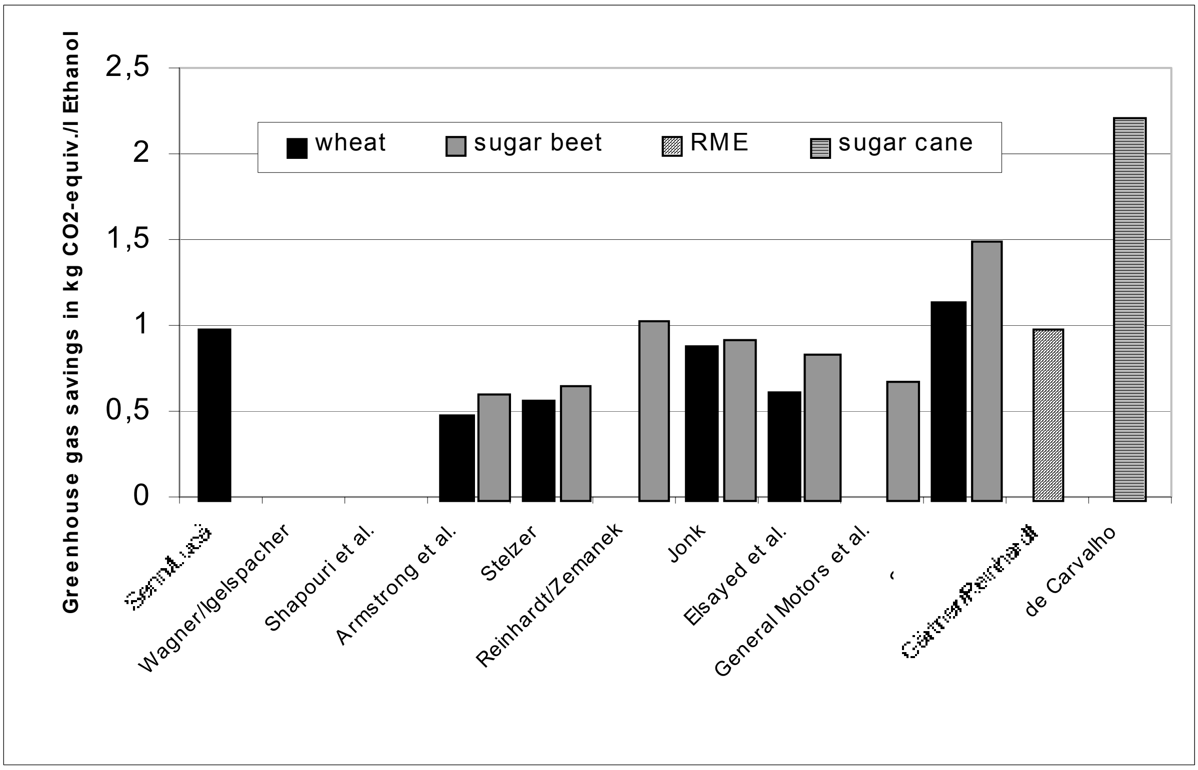

Figure 4: *Greenhouse gas balance – results from selected studies*

3 Energy and greenhouse gas balances for current and future production processes

The core of the study is the generation of energy and greenhouse gas balances for current bioethanol production facilities and for future production concepts. This was done for nine different production processes, five of which are already running in commercial practice and four are concepts of the future. These production processes were derived from the aforementioned seven producers from five different countries. For reasons of comparability it was assumed that the production units are based in Germany. Therefore the generated energy and greenhouse gas balances do not reflect the situation in the respective countries. However, they are based on the data of the production facilities in these countries. In each case the energy input and greenhouse gas emissions throughout the entire production chain of the final product bioethanol and also of its conversion to ETBE was evaluated. This includes the production of the agricultural feedstock, the provision of the bioethanol production plant, the conversion process and transportation. Operating supplies and by-products are also accounted for. The analysis is based on international standards for ecobalances.

Figure 5 summarizes the characteristics of the nine different production processes based on the energy concept and the resources used. Four production processes with a conversion solely based on fossil energy sources (lignite, natural gas and heavy fuel oil) and five also based on non-fossil energy sources (biogas and waste) are analyzed. The feedstock base of the different production processes include molasses, sugar beets, wheat, C-starch, different crops, and straw.

Conversion plants using energy from fossile sources	Conversion plants not using solely energy from fossile sources
Molasses (heavy fuel oil)	Cereals II (waste)
Sugar juice (lignite)	Cereals / Biogas I (mash fermentation, use of biogas)
C-starch (natural gas)	Cereals / Biogas II(mash fermentation, use of biogas)
Cereals I (natural gas)	Straw I (Diesel engines to grind straw, straw lignin and natural gas)
	Straw II (Diesel engines to grind straw, and solely straw lignin)

Figure 5: Bioethanol production plants according to feedstock and energy concept

Figure 6 shows the results of the energy balance. The first five bars result from production facilities that are actually in operation, the other four are based on concepts. Drivers of the energy input are the provided process energy, the agricultural production chains and the credits for by-products. Four of the five existing operations require between 12,3 and 14,8 MJ/litre fossil energy input. The cereals plant using waste as energy source requires only 6,7 MJ/litre (waste is not categorized as fossil).

The lowest fossil energy input is needed for cereals/biogas concepts and straw based ethanol production. In the cereals/biogas concepts mash is converted into biogas which then covers the energy demand of the conversion process. This results in net energy gains between 15.7 and 21.3 MJ/litre bioethanol for the cereals/biogas and the straw conversion.

The use of waste as an energy source leads to a net energy gain of 14.5 MJ/litre. Existing production processes based on different fossil energy sources and using molasses, C-starch and cereals as agricultural feedstock show a similar fossil energy input and achieve net energy savings between 6.4 and 8.9 MJ/litre. This also demonstrates that the conversion process of agricultural feedstock to bioethanol provides the largest potential for the optimization of energy balances.

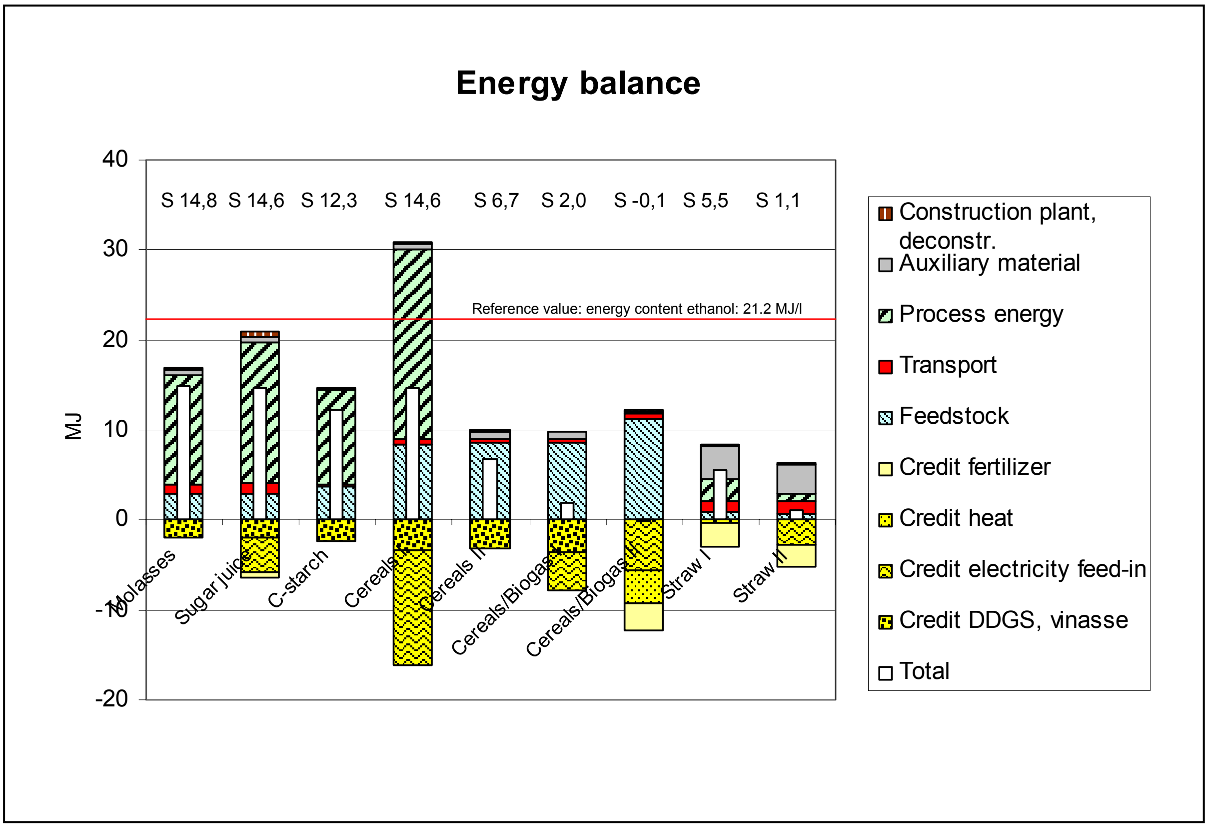

Figure 6: Accumulated fossil primary energy input in MJ per litre of bioethanol (figures above the single bars refer to the net effect)

Figure 7 provides an overview on the results of the greenhouse gas balance for the different production processes. The production of bioethanol based on straw generates the least greenhouse gas emissions due to the feedstock used and the low fossil energy demand for the conversion process. For this production option the greenhouse gas emissions amount to only 0.04 and 0.3 kg CO_2-equivalent/litre of bioethanol. Also the ethanol production based on wheat coupled with a biogas plant results in relatively low greenhouse gas emissions. Within the group of already existing plants the conversion processes based on C-starch and cereals with waste as energy source for the conversion provide the best performance. Here, emissions amount to 0,8 kg and 0,7 kg CO_2-equivalent/litre of bioethanol. The highest greenhouse gas emissions arise from the production based on sugar beet and the use of lignite as fossil energy source (1.6 kg CO_2-equivalent/litre of bioethanol).

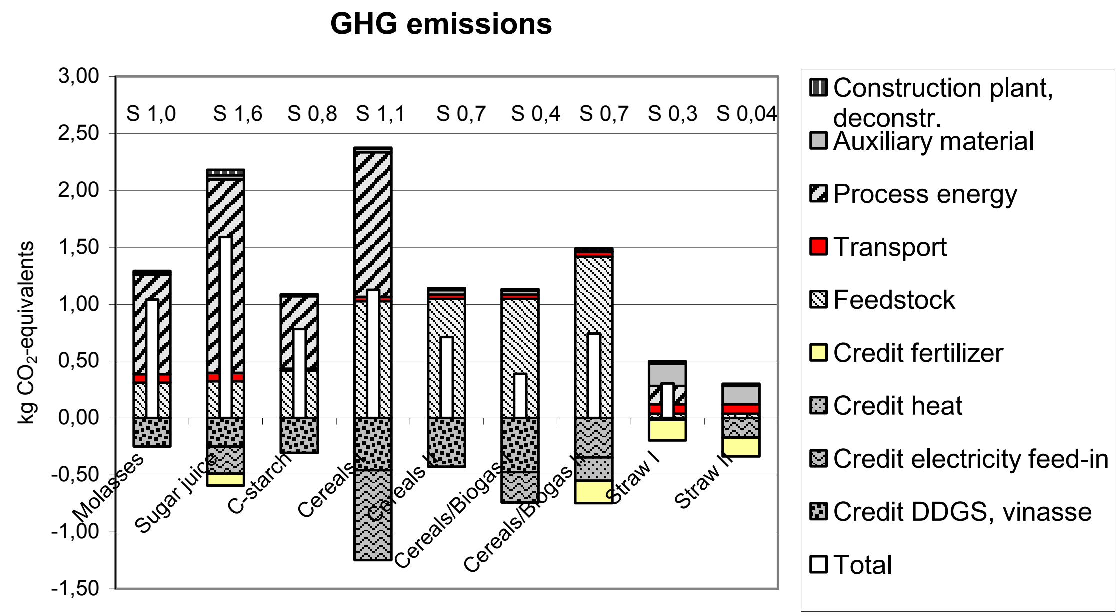

Figure 7: CO_2-equivalent emissions per litre of bioethanol (figures above the single bars refer to net-emisisons)

4 The production of bioethanol in Brazil

Brazil is the world largest producer of bioethanol. Ethanol production costs are low in Brazil, compared to Europe. Full production costs in Brazil range from 160 to 200 Euros per m³ whereas current costs in Europe are more than twice as high (450 to 500 € per m³).

Energy balances for the production of bioethanol in Brazil are quite impressive. This is due to the low need of mineral fertilizers in the cultivation of sugar cane and the energy surplus in the conversion process which results from the use of bagasse as an energy source. Therefore greenhouse gas emissions per litre of bioethanol are much lower than in Europe. The greenhouse gas abatement attained by the substitution of bioethanol for traditional gasoline ranges between 2 and 2,8 kg CO_2-equivalent per litre of bioethanol.

85% of Brazil's sugar cane production is concentrated in the centre-south-region, especially in the states of Sao Paulo and Paraná. The rest is produced in the north-eastern part of Brazil but under less favourable conditions. Currently the cultivation of sugar cane is only responsible for a relatively small part of the total farmland. Brazil has an arable farmland of 320 million hectares of which 53 million are in use today. Only 5.6 million hectares are used for the production of sugar cane.

Currently, about half of the sugar cane is allocated to the production of sugar, the other half to the production of bioethanol. In 2003, the crop yield was 350 million tons. Great fluctuations in the yields are mainly due to weather conditions.

There are about 400 bioethanol production plants with an overall capacity of currently approx. 17 million m³ per annum. With existing technologies the plants convert about two thirds of the sugar cane biomass. Currently, new technologies are being developed which can also extract bioethanol from the sugar cane straw which is mostly burned down on the fields today. Another incentive for the optimization of production processes is created by the new energy feed in law of the Brazilian government which allows for the electrification of the excess bagasse by the sugar and ethanol producers and for the feed in into the public electricity grid.

The blending of bioethanol into gasoline started with the Proálcool program after the first oil crisis in 1975. Today, there is no ethanol-free gasoline on the Brazilian fuel market. All gasoline is marketed with a 25% share of bioethanol (E25, also called gasohol. Actual ethanol content varies as it is yearly adopted to the market situation) and pure bioethanol (E100) is on the market as well. Since the end of the 80s consumption fluctuates around 12 million m³. Consumption of bioethanol as E100 declined between 1997 and 2002 but recovered in the last few years. Presently, about 14 million m³ of bioethanol are sold on the domestic market as E100 or E25.

For these two types of fuels there are three different types of automobiles on the market. First, for the use of the so-called gasohol ordinary gasoline engines need some minor modification. All automobiles on the market in Brazil experience no problems in the use of E25. On the contrary, the blending of bioethanol even improves the engine performance. Second, there are automobiles for the use of pure bioethanol (E100) which need more modification. Third, since 2003 so-called Flexible Fuel Vehicles (FFVs) are on the market. They can be run by E25 as well as by E100. This type turned out to be a major success. In 2004 FFVs already accounted for 30% of the newly registered vehicles and in 2010 the FFVs are expected to have a share of 25% of the entire Brazilian fleet. Therefore the mineral oil industry anticipates a major expansion of the domestic demand for bioethanol.

Due to the expected sharp increase in the domestic and international bioethanol demand investments in the bioethanol industry in Brazil and the development of new cultivable land is necessary in the short term. Therefore it is doubtable whether there will be a sufficient supply for the international market. There will also be a positive correlation between rising ethanol prices in Brazil and world prices for ethanol. This upward trend will be enforced if oil prices keep on rising. In addition, the infrastructure in Brazil is not insufficient which leads to high costs for logistics.

Comparison: Ethanol production in Brazil and in Germany

	Brazil	Germany
Feedstock	Sugar cane	Cereals (Wheat, rye, triticale), sugar beet, (potatoes)
Production capacity	approx. 17 mill. m³	approx. 300,000 in 2004, approx. 900,000 m³ in 2005
Production in 2003	14.4 mill. m³	approx. 280.000 m³
Production costs	approx. 0.20 - 0.25 US$/litre	approx. 0.45 – 0.50 €/litre
Net energy gain	18 MJ/litre	Currently 7 MJ/litre, with new technologies between 15,7 and 21,3 MJ/litre
GHG avoidance	2 – 2.8 kg CO_2equivalents /litre ethanol	Currently up to 1.1 kg, with new technologies up to 1.8 kg CO_2-equivalents/litre ethanol

Figure 8: Ethanol production in Brazil and in Germany

However, as the use of bioethanol is promoted by politics in a rising number of European and Asian countries the increasing worldwide demand for bioethanol will be the decisive opportunity for the Brazilian ethanol industry. For example, countries like Japan or Korea will depend on imports as their domestic production is not able to satisfy the increasing demand. Also exports to the US are of rising importance. Nevertheless, it is well known that in the past prices for the Brazilian bioethanol have been extremely volatile due to fluctuating demands, crop yields and relative prices between bioethanol and sugar. As there are currently no other major exporting countries with a high potential in the production of bioethanol these are some major risks for countries that become dependent on the import of ethanol from Brazil.

5. The dynamics of the European bioethanol market

The size of the future bioethanol market in the EU will directly depend on how much bioethanol will be blended into gasoline and on how much ETBE will be produced.

The sales of gasoline in 2003 in the EU-25 amounted to approx. 117 mill. tons. The five largest markets for gasoline are Germany, Great Britain, Italy, France and Spain. In these countries about three fourth of the entire gasoline is consumed. Especially in Germany there is a distinct decline in gasoline consumption which is due to increased use of diesel vehicles, declining consumption per vehicle and also declining mileage per car. Whereas in Germany consumption was about 30 million tons in 2000, 4.2 million tons less were consumed in 2003.

According to current gasoline standards up to 5% bioethanol by volume can be blended into traditional gasoline. This leads to a theoretical market potential of about 1.7 million m³ of bioethanol in Germany. The direct blending of bioethanol requires the solution of the vapour pressure problems and a coordinated approach by the mineral oil industry due to the swap practice.

Compared to direct blending of bioethanol, the advantage of ETBE is that this product is broadly accepted by the fuels and the automotive industry.

The EU-25 has a total MTBE and ETBE capacity of approx. 5.2 mill. tons. Since the beginning of 2004 ETBE is produced in one refinery in Germany. The transition from MTBE to ETBE production at the other production facilities is currently taking place so that from 2005 onwards mainly ETBE instead of MTBE will be produced in Germany. The overall EU market potential is 3.1 million m³ bioethanol if all facilities work to capacity. Capacity expansions are unlikely.

In 2003 about 280.000 m³ ethanol have been produced in Germany. In 2004, production decreased slightly. Germany accounts for approx. 10% of the European production. The ethanol sector is characterised by the Federal monopoly for ethanol, small and medium-sized producers and the second largest production plant of synthetic ethanol in Europe. Imports continue to rise and increasingly pressurize domestic producers. German export of ethanol is dominated by synthetic ethanol and only makes up for one third of the imports with a declining trend.

For the future of the German ethanol market the new large-scale production plants are more important than the existing plants. Südzucker and Sauter have put up three new large-scale plants in the New Laender with an overall capacity of about 540.000 m³. All plants are expected to produce in 2005. In addition to these large-scale plants some more small and medium-sized plants are in the construction process or planned. Thus, the overall production capacity in Germany will be around 900.000m³ in 2005.

The capacity of the large-scale plants is more than enough to satisfy the bioethanol demand for the production of ETBE. Assuming a production of 600.000 tons of ETBE this would create a demand for bioethanol of about 360.000 m^3. Only direct blending creates a market size which is sufficient to absorb the ethanol produced in Germany.

The international competitiveness of the German ethanol production could be enhanced by using the benefits the Act on Renewable Energy Sources (EEG) offers. The production of biogas during the bioethanol production process coupled with a combined heat and power generation would allow to benefit from the high feed-in tariffs as provided by the EEG. In agricultural distilleries this is already possible due to relatively low capacities and the existing technologies. For large-scale industrial bioethanol production plants this is not possible with current technologies and innovative production processes are necessary.

The further expansion of German production capacities depends on future EU-Mercosur trade negotiations and possible trade liberalizations within WTO negotiations. Uncertain political framework conditions especially about future tariffs put possible investments on hold.

So far, the growing market for diesel as another possibility to increase sales of bioethanol has not been considered. However, “Diesohol”, a mixture of diesel with bioethanol, might be another interesting option that could increase the market for bioethanol considerably.

The further introduction of FFVs could be another driver for bioethanol markets in Europe. First initiatives have already been started. FFVs allow for a conscious decision of consumers for renewable fuels and they increase the visibility of biofuels in the market.

Altogether, one can expect that in the years to come international trade with bioethanol will rise sharply. Demand in important countries like the USA, China, Japan, Korea and India rises considerably. High oil prices will also support this development. Brazilian experts estimate that Brazilian exports will rise from about 900.000 m^3 in 2003 to about 2 million m^3 in 2004 and to a minimum of 3 million m^3 in 2010.

The intensity of competition and the price level in the European bioethanol market in the future will mainly be determined by political decisions. A reduced protection from international trade and the granting of import quotas will lead to a downward pressure on prices. Currently, European producers cannot compete against producers from Brazil. In a free market they would drop out of the market and a further expansion of the European bioethanol industry would not take place.

In Germany the exemption of biofuels from the gasoline tax was justified by an alleged positive effect of biofuels on climate, energy, agricultural, employment, and structural policy goals. If rising imports do not allow for an expansion of the German bioethanol industry most of these goals will not be achieved.