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Considerations on the worldwide use of bioethanol as a contribution for sustainability

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Abstract *The use of ethanol from biomass as a gasoline substitute in cars and light trucks is possibly one of the most attractive and feasible alternatives to deal with global warming. As environmental concern grows, many countries are increasing their efforts to consolidate bioethanol processes and supply. The sustainable production of bioethanol requires well planned and reasoned development programs to assure that the many environmental, social and economic concerns related to its use are addressed adequately. The key for making ethanol competitive as an alternative fuel is the ability to produce it from low-cost biomass. Many countries around the world are working extensively to develop new technologies for ethanol production from biomass, from which the lignocellulosic materials conversion seem to be the most promising one. This paper aims at providing some information about the status of bioethanol production and use around the world.*

Introduction

Annual world production of fuel ethanol is about 26 billion liters, from which Brazil is responsible for about 60 percent, followed by the USA and China. Roughly 60 percent of world bioethanol is produced from sugar crops, mainly sugarcane and sugar beet; the remaining comes from grain, mainly corn (Berg, 1999).

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Many developed and developing countries such as Japan and India are considering ethanol as the most adequate fuel for octane enhancement and as a gasoline substitute, in different proportions (Figure 1). Despite the existing commercial barriers and the absence of regulatory mechanisms, the evolution of international agreements has led conducted to vigoros actions toward:

- decreasing imported oil dependence, promoting a policy for energy self-sufficiency in liquid fuels, and redefining the importance in energy geopolitics, so important nowadays;
- recognizing environmental awareness to decrease the gases emissions responsible for the greenhouse effect – mainly CO_2; and
- improving air quality, especially in large cities – a problem which is becoming a main concern by the public, particularly in the developed countries.

Several initiatives have been implemented in different countries, such as The Netherlands, Sweden, France, Spain, the USA, Canada, China, Japan and Australia, stimulating production and exports – or even imports – of bioethanol (Berg, 1999).

Why is bioethanol the way to go?

Bioethanol is perhaps the most attractive short- to medium-term alternative for gasoline in cars and light trucks because it reduces the use of gasoline. Therefore, bioethanol can be important in lowering greenhouse gas emissions, improving environmental and economic sustainability.

In a recent study, Lave *et al.* (2001) pointed out three technologies having the potential of reducing net emissions by motor vehicles: batteries, fuel cells, and ethanol. Each of these technologies has their own advantages and drawbacks and none is in reality a “perfect put-in substitute” for the present worldwide fossil fuel model. The point is that the up to now successful “fossil fuel model” is the cause of serious environmental problems, requiring a short- to medium-term solution or at least a reasonable remedy. In the analysis presented by Lave *et al.* (2001), the existing individual vehicle transportation model itself is not being questioned. They proposed that instead of inducing consumers to choose more efficient vehicles for personal transportation through higher taxes on gasoline consumption, bioethanol could be used in different proportions as an alternative to gasoline. That is to say, let consumers continue choosing their “fuel-hungry” sport utility vehicles (SUVs) and light trucks (which account now for more than half of new vehicle sales in the USA), but induce them to turn to ethanol as fuel. The rationale is that efficiency arguments do not apply in general to consumers’ choices on vehicles for personal transportation. Any improvement in engine efficiency ends up just as a further incentive for consumers to buy vehicles with more powerful engines. That is not to say efficiency initiatives should be neglected. Each of these

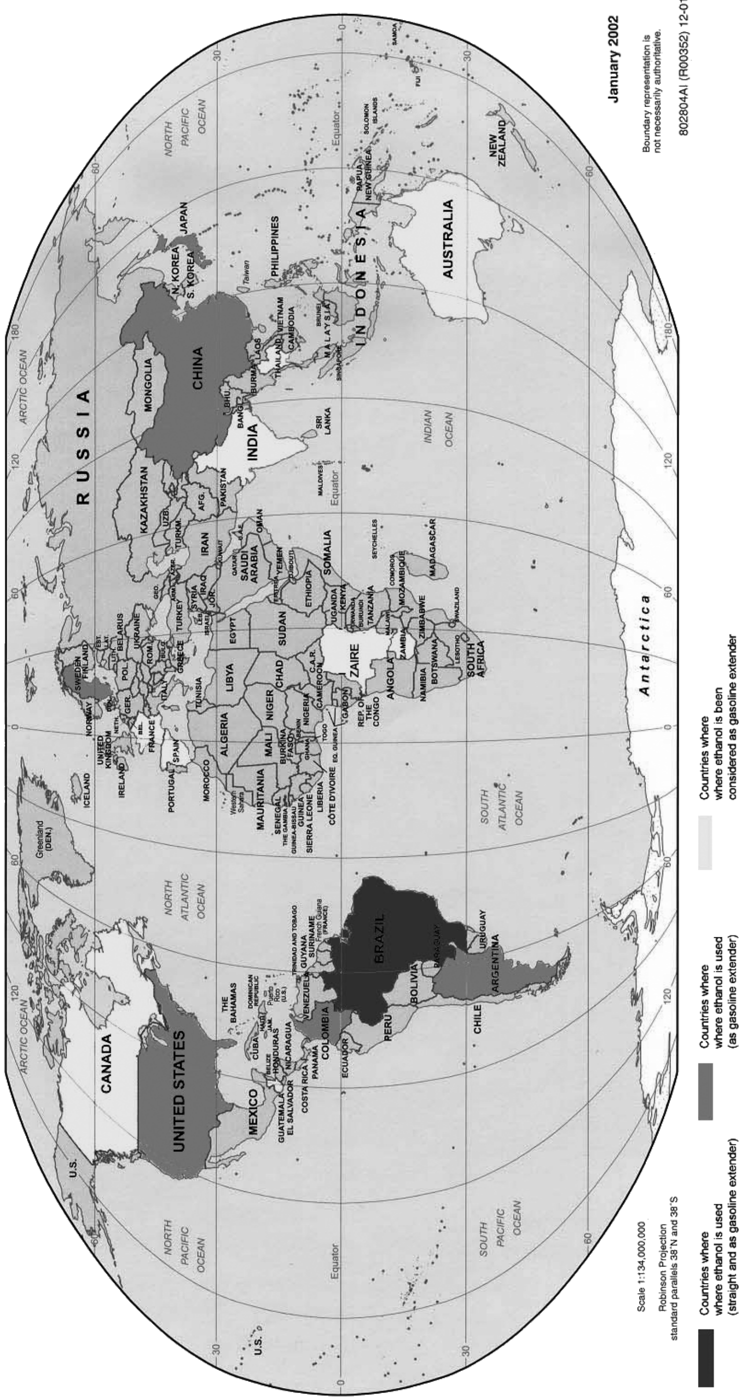

Figure 1.
Situation of bioethanol use in the world: straight and as gasoline extender

technologies mentioned above is briefly discussed below, having in mind the zero-CO_2 emissions target.

Batteries

Charging batteries requires producing electricity. In this respect, it is important that the source of primary energy be renewable, such as hydro or biomass[1]. Unfortunately battery-powered cars are expensive and represent a potential public health menace. To get even a 100-mile range, about 500kg of batteries are required for a two-passenger car. Making and recycling these batteries is expensive, leading to large increase in the cost of driving. If the current US fleet of 200 million vehicles was run on current lead acid, nickel cadmium, or nickel metal hybrid batteries, the amount of these metals discharged to the environment would increase by a factor of 20 or 1,000, raising vast public health concerns (Lave *et al.*, 2001).

Fuel cells

Fuel cells basically emit water vapor and are much more efficient than internal combustion engines. Unfortunately, fuel cells are still extremely expensive, and they cannot compete with current engines. Major technology breakthroughs are required to make fuel cells attractive for light vehicles. Also, the environmental implications of the fuel cells cannot be known until we know what material and processes will be used and how hydrogen will be produced (Lave *et al.*, 2001).

Ethanol, the way to go!

Ethanol gives a relatively "clean" combustion because the CO_2 delivered back to the atmosphere is extracted in the photosynthesis process. Because ethanol can be continuously produced in the long term, it is generally accepted that it can be considered a fairly renewable fuel. Also, ethanol can be produced economically, at least in some parts of the world, such as Brazil. Ethanol has been produced in Brazil in large scale since the beginning of the Proalcool (Brazilian National Alcohol Program) in 1975 (Rosillo-Calle and Cortez, 1998). Year after year sugarcane has been cultivated yielding high biomass production at low costs. Presently Brazil produces the lowest cost ethanol in the world (about US\$200/m^3). Neat ethanol is distributed it in the whole at about half the price of gasoline, without any government subsidy.

Therefore, if fuel ethanol presents these advantages and is competitive in Brazil, the questions raised here are the following. Is it possible to produce ethanol in large scale in a sustainable way? What are the limits? Could other countries adopt a fuel ethanol model similar to the one in Brazil?

One important key point, often considered as a drawback of the renewable ethanol model in relation to its fossil fuel counterpart, is that the production of bioethanol requires growing raw material. This is an important issue to be considered when it comes down to decide if the fuel ethanol model can be applied globally. Feasible alternatives for large-scale production of raw materials required to produce enough fuel for the individual transportation sector are discussed below.

Raw materials for large scale ethanol production

Ethanol can be produced from sugar, starch and fiber. Yet the major source of ethanol currently is fermentation of sugar from sugarcane and corn. Although sugarcane ethanol became very competitive in Brazil, sugarcane is planted mainly for its sugar content. The ethanol technology advanced significantly in the last 25 years since the introduction of Proalcool, but is not likely that we can depend on this technology to achieve more ambitious targets such as producing a worldwide alternative fuel. The USA uses basically corn to produce ethanol, which is highly subsidized (US$0.54 per gallon).

Fiber is the most abundant raw material available worldwide for ethanol production. It can be obtained economically from sugarcane, agricultural residues and other dedicated crops such as eucalyptus. Lignocellulosic materials can be cultivated, harvested and processed so that there are no net carbon dioxide emissions. Environmental quality can be enhanced as a result – less erosion, less use of chemicals and water and less soil loss.

The technology to convert lignocellulosic materials into ethanol is the hydrolysis process, which has not been fully developed. The use of lignocellulosic materials as a source of sugars for the conversion to ethanol is rapidly developing, particularly in the USA and Brazil.

The Brazilian experience

The use of fuel alcohol in Brazil dates back to the 1930 decade, when ethanol was first blended to gasoline thus providing a "sink" for excess sugar production.

In 1975 the Brazilian Government launched the Proalcool, an innovative initiative for promoting ethanol as a large-scale substitute for gasoline. In the late 1980s about 95 percent of new passenger cars were powered by ethanol.

The country carried out a large R&D program to modify the Otto engine to fuel ethanol, accumulating expertise and know-how in its production, supply and applicability. Productivity increased from 3,900 liters/ha in 1980 to nearly 5,600 liters/ha in 2001[2]. Annually, Brazil produces about 13 billion liters of ethanol at the lowest cost in the world (US$200/m^3). It is possible to reduce costs even more, by about 13 percent in the next six years.

Sugar producers have proved to be highly influential in Brazilian politics and this explains constant concern shown by government in providing relief for the industry surplus. In the early 1970s, a serious global energy shortage crisis was the pretext for the Brazilian military regime – which regarded energy supply as a high priority in its national security agenda – to launch Proalcool.

In the beginning of the 1980s the country was highly indebted when it was overtaken by a serious foreign exchange crisis. A second oil price shock then made investments in new ethanol plants to increase and production grew rapidly between 1980 and 1985, reaching around 10 billion liters/year, enough fuel to fill the tanks of the more than 4 million neat ethanol-fueled cars and to be blended with gasoline for the remaining vehicle fleet.

The second half of the 1980s was marked by a relief in world oil prices and stagnation in ethanol production took place. It was also the time Brazil had new priorities, as the country suffered several stabilization programs in a row aimed at controlling an ever growing inflation. Despite of that, demand for ethanol continued to grow and the unbalance between a rigid supply and an increasing demand culminated with the 1989 supply crisis, which forced the government to import methanol.

This crisis was a serious drawback to the program and caused many vehicle owners to reject new ethanol-fueled cars. The number of neat ethanol vehicles produced has plummeted since then and represents less than 2 percent today. Therefore, all of the ethanol produced by the country in the 1996/1997 season – nearly 13.7 billion liter/year, replacing about 200,000 barrels of petroleum/day and avoiding approximately 26 million metric tons of CO_2 emissions annually – was either used to fuel relatively old vehicles (generally pre-1990 vintages) or to blend with gasoline at a 22 percent volume content.

Today Brazil produces nearly 300 million tons of sugarcane, roughly 50 percent of it dedicated to ethanol production. Brazilian ethanol production is around 13 billion liters annually, an output level kept constant since the 1989 crisis. Although hydrated ethanol (E100) use is declining as a result of the consumer skepticism, the supply of anhydrous ethanol blended with gasoline (E24) is increasing at a compensating rate.

It is anticipated that oil prices may rise in the neat future as a consequence of the current crisis in the Middle East, causing gasoline prices to increase to a point it can lead to a revival of consumers' interest for neat ethanol vehicles.

The US experience

The USA has been using ethanol as fuel since at least 1908. Production has increased enormously since the oil supply disruptions in 1980 decade. Ethanol production grew from 665 million liters in 1980 to 7 billion liters in 2000, supported by federal and state tax subsidies.

Demand for ethanol could increase even further should methyl tertiary butyl ether (MTBE) – an oxygenating additive – be banned. About one-quarter of global MTBE production is directed to the state of California, which already has announced plans to discard it.

In 1990 the President of the USA signed the Clean Air Act Amendments (CAAA), regulating the use of reformulated, oxygenated gasoline, mainly in highly polluted regions, especially during the winter months. According to this document, a certain proportion of the oxygenated fuels should derive from renewable sources, ethanol becoming the best choice. The government intervention was not only limited at the political sphere. Several incentives were offered to farmers, such as tax exemptions – both at federal and state levels – and special credit programs. In January 1991, tax exemption was set at 5.4 cents/gallon for a minimum share of 10 percent of ethanol in the mixture, representing 54 cents for each gallon of ethanol. In 1998 the government approved a law extending the benefit until 2007. Subsidy rate is to decline steadily, reaching US$0.51 in 2005. These actions have stimulated investments in ethanol production, which are likely to increase the US output capacity by 60 percent – from the present about 7.5 billion liters to approximately 11 billion liters – in the next two or three years.

Ethanol production and use in other countries

The EU has demonstrated its commitment to reduce the greenhouse effect and is working seriously to stimulate the use of fuels derived from renewable sources of energy[3].

Tax exemptions for biofuels used in the transport sector has been a key instrument to reduce gas emissions in The Netherlands and other European countries.

France is producing ethanol from plants containing sucrose, beet for instance, or starch, such as cereals and potatoes. The resulting ethanol can be added to fuels in a pure form or as ETBE, a chemical composition obtained from the reaction of ethanol (45 percent) and isobutylene (55 percent) (Berg, 1999).

The Swedish Government has spent over US$4 million in the last three years to demonstrate the advantages of renewable fuels. By 2010, Sweden will have 15 percent of its transportation fleet using fuels produced from biomass. The Swedish Foundation for the Development of Ethanol – founded over 15 years ago – is working on different projects for producing ethanol from residues originated in the paper and forestry industries (Berg, 1999).

Spain, a major ethanol producer in Europe, is increasing its participation by buying new ethanol plants in the USA (Berg, 1999).

China is increasing ethanol share in gasoline to the 10 percent level. Current annual ethanol production of 2.7 billion liters should reach 4 billion liters as a consequence. Most of its ethanol is produced from sugar crops, corn and sugar beet. The USA has taken several investment projects there to produce ethanol from corn (Berg, 1999).

Japan is also developing an important program to add ethanol to diesel. It has formed a group denominated Global Alliance with countries such as Canada, Australia, Thailand and Guatemala, having as objective the trade of fuel ethanol (Berg, 1999)

Other countries, such as Argentina, Colombia, India, and Mexico, among others, are introducing smaller scale fuel ethanol programs (Berg, 1999).

Worldwide production of ethanol

The supply of bioethanol at a global scale increasingly requires further actions to promote its production at low cost using raw materials presently available in the world.

It would be necessary more than 2 trillion liters of ethanol to replace the present gasoline consumption in the entire world. As a reference, up to 400 million hectares of land dedicated to energy crops would be required for Brazil only to produce this huge amount of ethanol using current best practices. This would represent an immense expansion of ethanol production in the country and a well planned and reasoned development program would be necessary to assure that the many environmental, social and economic concerns are addressed properly.

Today, bioethanol can be produced using sugarcane in countries like Brazil, corn in the USA and China, and beets in the EU and China. Besides that, the use of lignocellulosic materials as a source for converting sugars to ethanol is being developed at a certain speed. It is expected that enzymatic hydrolysis will be commercially available in the next ten years, allowing the use of agricultural residues such as corn and sugarcane residues, abundant and produced at relatively low costs in the USA, Brazil, China and India, to name a few countries. More applied research in hydrolysis needs to be done to speed up the technology development.

Market strategies for gasoline substitution

Ethanol can be used as an additive for gasoline (anhydrous ethanol), giving an oxygenated fuel with a greater octane number, and to fuel neat ethanol (E100) vehicles (hydrated ethanol). In Brazil, anhydrous alcohol is added to gasoline at a 20 percent-26 percent proportion in volume. In the USA a mixture of gasoline (90 percent) and ethanol (10 percent) (E10) – the so-called "gasohol" – has been used for more than two decades. In both countries the decision to blend ethanol with gasoline was highly motivated by political pressures exerted by farmers to compensate for their losses in sugarcane and corn markets.

The market for ETBE and MTBE

Oxygenates, such as ethanol, MTBE, ethyl tertiary butyl ether (ETBE), and tertiary amyl methyl ether (TAME), have been added to gasoline to make the combustion cleaner, consequently reducing toxic pollution, particularly CO. Ethanol is a base chemical used directly as additive or in ETBE production. The extensive use of ethanol and ETBE could boost the use of renewable fuels, having a significant impact on the atmosphere. The demand for ethanol may also increase if MTBE is banned in the USA. Presently, the USA imports around 80 percent of the MTBE utilized in the country. It is estimated that by 2010 approximately 6 percent of the fuel consumed in the USA will come from renewable sources, making ethanol demand to reach 20 billion liters/year (DiPardo, 2002; Renewable Fuels Association, 1999; Urbanchuck, 2001). However, the best oxygenating additive could be ethanol itself; accepting the concept of E10 to E85 flexible engines will resolve completely this issue.

International market for ethanol

The volume of ethanol traded in the world today is still very small compared with fossil fuels. Agricultural raw materials necessary to produce bioethanol represent nearly 70 percent of the final fuel costs. Therefore, the agriculture phase matters most. This partly explains why Brazil is competitive in producing low cost ethanol from sugarcane, a crop well suited for extensive production in the country, at least up to the present output level. Also the USA produces a significant amount of bioethanol, although it has been doing it with high and unsustainable long term subsidies. The US ethanol production from high cost corn to substitute low price gasoline constitutes a situation difficult to be held in the long run.

Therefore, Brazil and a few other tropical countries may have absolute and comparative advantages in producing bioethanol surpluses to meet high levels of consumption in the global market. Probably the major difficulty to implement an international market for ethanol is the barrier created by influential local farmers, which tend to treat any foreign agricultural commodity as a serious threat to them. American and European strategists also regard their agricultural sector as important to their national security policies[4].

It is important to mention that any strategy aimed at the creation of a large international market for ethanol should associate it with energy, not with agricultural commodities. For instance, ethanol entering the USA should be seen as a substitute for imported oil, not for the alcohol produced from the corn supplied by local farmers. It should be a "crowding in" situation with respect to domestic agricultural producers if the ethanol initiative is to succeed.

If large volumes of fuel ethanol cannot be traded among countries, what could eventually be done? A possible strategy may be first to encourage the built up in some countries of a strong local fuel ethanol market by decreasing the risk of supply. The creation of a strategic large stock of ethanol kept at a certain level to be used by any country as needed. Brazil will probably have an extra 2-3 billion liters of ethanol/year in the next coming years. This surplus could be used to create a 5 billion liter regulatory stock, enough to avoid a major supply crisis in a future global ethanol market. Another objective of the proposed regulatory stock of ethanol is to assist newly created markets, such as China and India. Bioethanol can become, in fact, an important element for sustainable development, as presented below.

The Clean Development Mechanism

The Clean Development Mechanism (CDM) has attracted worldwide interest since it was proposed during the negotiations of the Kyoto protocol. CDM projects allow developing countries to sell carbon certificates to countries that have agreed to reduce CO_2 emissions. CDM can be considered an important instrument to lessen global warming. Yet it does not necessarily assure environmental and economic prosperity at a global scale. It is well known that the main aspiration of most developing countries is to achieve sufficient economic development to satisfy not only their basic needs but also to close the gap with the more developed countries. This would require more and more energy inputs and investments. In the last decades, notably after the Second World War, the developing nations experienced a surge in economic growth with a corresponding fast increase in energy consumption, which prompted them to abandon traditional low energy biomass and use more imported fossil fuels. This caused many developing countries to undergo foreign exchange crises, which in some cases led to political instability, threatening long-term global economic prosperity.

Trading renewable energy sources, such as bioethanol, wood, agricultural residues, and vegetable oils, may be an important mechanism for integrating developing countries in the global economy. However, protective actions taken by many developed countries make it difficult.

Nearly 60 percent of the Brazilian energy matrix is composed by renewable sources, mainly hydro (40 percent), burning wood and charcoal (10 percent) and sugarcane (10 percent). Brazil has an external debt of US$400 billion; it takes nearly US$30 billion per year just to finance it. But the country has faced trade barriers for the goods it produces that are difficult to overcome. For instance, its charcoal based steel has been recently heavily taxed by the USA and EU. CDM projects could be an important alternative to trade for Brazil and other developing countries to pursue sustainable development.

Complementary studies to increment ethanol production

There are serious key problems to be solved for implementing a large-scale worldwide fuel ethanol model. How much land and how much of the natural resources would be necessary to produce such a huge quantity of ethanol? What about fertilizer availability? What will be the impact of pests on a much larger sugarcane area? Is capital available for the required investment in distilleries? Is the technology to produce fuel ethanol from low cost lignocellulosic materials feasible? What are the environmental impacts? Is the idea politically sound after all?

Studies on the sustainability aspects

Producing ethanol in a large scale deserves a thorough interdisciplinary study considering the impacts on the environment, labor, and economy. Today, the cultivated area devoted to sugarcane in Brazil – the leading sugar and ethanol producing country – is about 5 million hectares. The culture of soybean and corn requires nearly 13 million hectares of land each. Some specialists claim that increasing cultivated area of sugarcane from 5 to 13 million hectares could be accomplished without any significant negative impact on the environment. Other specialists claim that sugarcane crops could take us much as 40 percent of Brazilian territory, representing nearly 300 million hectares. However, a more in-depth study is required to implement any large scale project for ethanol production in Brazil (Cortez *et al.*, 1998).

Studies on fiber collection and hydrolysis for converting fibers into ethanol

Besides the already mentioned sustainability issues there are other important limitations to be considered. The USA and Brazil are firmly engaged today in conducting applied research to produce ethanol from lignocellulosic materials. The hydrolysis technology would allow Brazil to supply large volumes of bioethanol to countries with limited natural resources — land and water inputs, for instance. However, there are still significant technical barriers preventing the use of fibers for ethanol production. In Brazil the use of sugarcane trash – not available today because most of sugarcane is still burned prior to harvesting – could be feasible if harvest technology progress to a level of collecting trash at a much lower cost (Braunbeck *et al.*, 1999). At the present stage trash can be processed and delivered to sugar and ethanol plants at a cost of US$10 per metric ton (dry matter). It is also necessary to address the problems involved in converting lignocellulosic materials into ethanol, mainly the development of the whole technological package of enzymatic hydrolysis and the adaptation of the "diluted acid pre-treatment" process to accomplish simultaneous saccharification and fermentation, a process named SSF. Also it is necessary to conduct studies to implement and configure a pilot plant in Brazil.

Conclusions

The main issues addressed in this paper were the implications of a worldwide large scale production of bioethanol to replace fossil fuels currently used by light duty vehicles. The advantages, difficulties, and perspectives were discussed. Possibly the best long-term strategy is to create an international market for fuel ethanol, promoting it in such a way to form a "renewable fuel mentality" particularly in the developed nations. Another important aspect is to stress the environmental benefits of bioethanol in reducing the greenhouse effect in CDM projects. Many developing countries could benefit from the bioethanol initiative, helping them to achieve progress and stability in a more equitable world.

Notes

1. Nuclear technology also produces zero-CO_2 emissions but cannot be considered a feasible alternative for worldwide electricity generation. The main difficulty to increment nuclear technology is its negative image summarized in the popular say “not in my backyard”.
2. In southern Brazil, where 65 percent of sugarcane is produced, the productivity may reach up to 6,500 liters/ha per year.
3. Text based on Berg (1999).
4. According to personal communication from the Brazilian Agribusiness Association (ABAG) the ethanol from Brazil is taxed 2.5 percent in addition US$0.54/gallon resulting in a tariff near 50 percent.

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