# BIOFUELS AND DEVELOPMENT: THE THIRD DIVIDEND [*]

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The growing world interest in biofuels in the past few years can be explained by several factors. High crude oil prices, local and global environmental impacts of fossil fuels, and geo-political issues have raised attention to alternative fuel sources. The less-than-full utilization of agricultural potential in many countries has also led to a push by domestic interests toward finding new outlets for its productive capacity.

Ethanol is the outstanding biofuel that has benefited most from this recent surge in interest. It can be produced from a variety of feedstocks such as cereals (corn, wheat) and sugar cane. Brazil (sugar cane) and the US (corn) are responsible for 90% of the world production. Ethanol as a fuel for transportation currently corresponds to about 1.2% of the world's gasoline consumption by volume, with this percentage falling to 0.8% when measured by transport distance traveled because of its lower energy content. Global ethanol production more than doubled between 2000 and 2005.

Biodiesel - mainly made from rapeseed or sunflower seed - has roughly quadrupled in the same period, but departing from a much smaller base. The European Union produced 89% of all biodiesel worldwide in 2005, with Germany accounting for 1.9 billion liters or more than 50% of the world total. A major novelty in the scenario has been the emergence of developing countries as competitive producers of biodiesel (Thailand, Malaysia etc.) made from palm oil, jatropha, castor beans, soy beans and others.

This note highlights the potential for another driver toward higher use of biofuels for transportation on a global scale, namely the opportunities for development that it can generate as an outlet for using currently idle or underemployed human and natural resources in poor countries. Additionally, after revisiting the major current concerns that are driving attention and policy support to biofuels – energy security and environmental impact of fossil fuels – we try to illustrate how they would be further addressed if such a development-oriented truly global adhesion to biofuels takes place. In a nutshell, biofuels may offer a triple dividend: higher energy security, cleaner and lower-carbon environment, and more economic development.

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## 1. Energy security as a driver toward use of biofuels

Despite recent falls oil prices have remained high in the last 4 years as compared to levels prevailing from the 1980s until 2003 (Figure 1), and most oil market analysts are not expecting any return to the latter prices in the foreseeable future, as illustrated by the resistance of long-run prices in future markets (Figure 2). Demand for oil tends to remain strong as energy-hungry developing countries increase their weight in global growth, whereas one can point out several factors that tend to make sluggish the process of investments and rebuilding of spare production capacity in the following years (Mauldin, 2007). Even if oil prices are to cross another soft patch in the medium run, their characteristic volatility will remain.

Those developments in oil markets have constituted a powerful market-driven incentive favoring substitutes for gasoline and diesel, including biofuels. In their turn, these market signals have also been – or are about to be - reinforced by public policies adopted in several countries, such as mandated fuel content requirements and/or biofuel use targets.

FIGURE 1

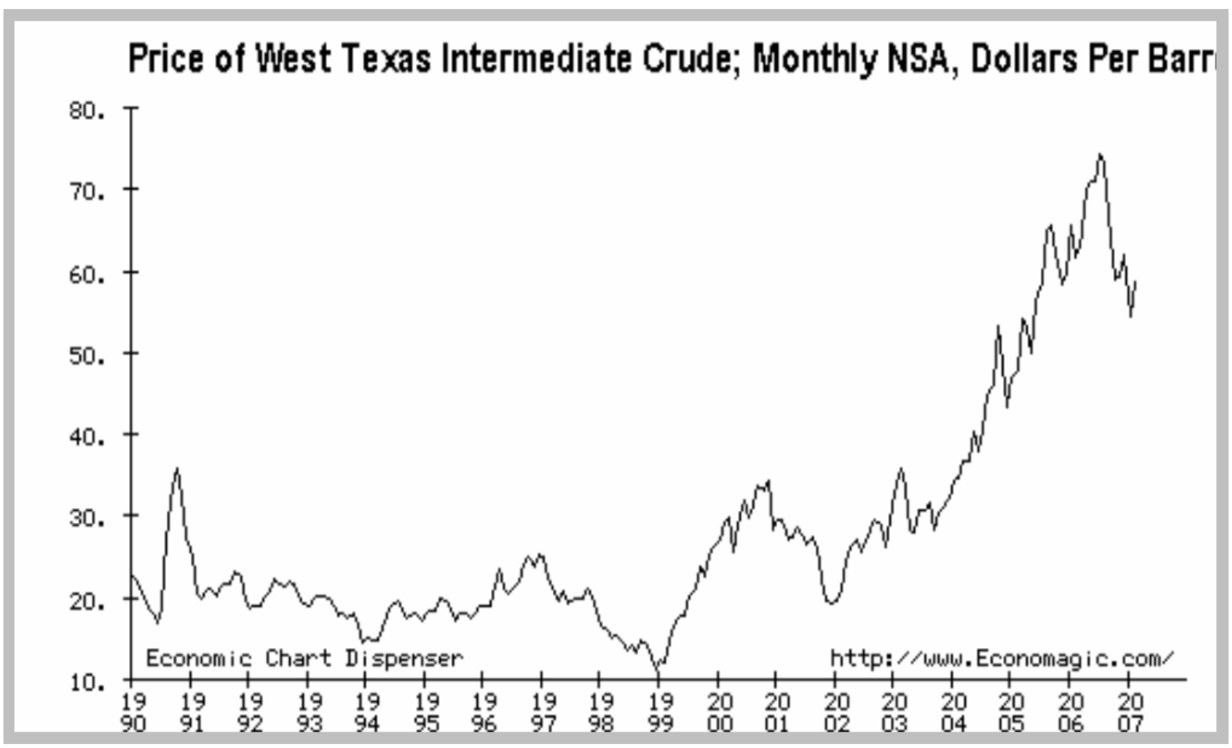
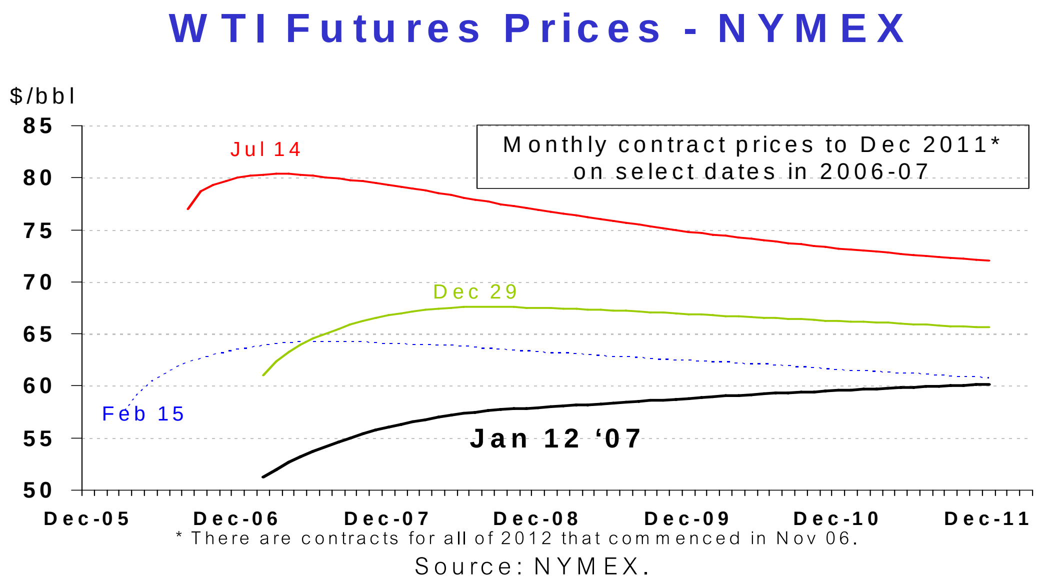


FIGURE 2




Elaboration: DECPG Commodities Group, World Bank

"Energy security" has been referred in several cases as a motivation for those policies. After all, oil price hikes in the recent past have been strongly correlated with geo-political events associated to oil-producing countries. Given the high oil-import dependence of the major economies and their corresponding vulnerability vis-à-vis accidental or purposeful supply disruptions and price shocks, switching - or at least diversifying - energy sources out from oil has become a frequently declared priority.[2]

However, different meanings can be attached to the energy security pursued with those policies. One of them is a misidentification with "self-sufficiency", as in cases in which a strong support from domestic interests hoping to benefit as providers of energy import substitution ends up capturing the policy-making in a zero-import-target trap.

Broader definitions of energy security, on the other hand, will lead to policies different from "autarky". For instance, Barton et al (2004) suggest energy security as "a condition in which a nation and all, or most of its citizens and businesses have access to sufficient energy resources at reasonable prices for the foreseeable future free from serious risk of major disruption of service" (p. 5). As these authors show at length, this characterization of energy security in the context of the recent decades of global economic integration has necessarily to encompass: (i) management of complex and far-flung infrastructures (integrity of networks in relation to fuel supplies, capital expenditure, short term reliability, and the ability to withstand intentional and unintentional damage); (ii) market competition (after the break-up of monopoly suppliers that has led to higher efficiency); (iii) related to the previous two aspects, international trade and investments in energy; and (iv) interaction with environmental constraints.

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2 See Sandalow (2007) for the case of the United States.

A systemic approach that comprehends diversity of forms of energy supply, as well as diversity of both domestic and foreign sources is at the essence. “Autarky” may run against security in modern integrated economies, as it impedes the functioning of market mechanisms in the three ways by which they can increase energy security: (i) the use of the market tool of prices to discourage waste; (ii) the role as a shock-absorber, that is enhanced the bigger the market; and (iii) experimentation and selection of alternative applied technologies, the universe of which depends on the scope of potential sources of supply.

One must reckon with the fact that security will likely imply a cost derived from diversity of energy sources, as some less efficient and more costly energy alternatives might be kept in use in order to avoid over-dependence upon the best ones. These costs are to be seen as a “premium” paid for guaranteeing that the economy will not be completely locked in technological trajectories associated with dominant energy sources (as it occurred in the case of oil along the 20th Century). This premium can only be minimized if a “non-autarkic” approach to energy security is prevalent, as forced self-sufficiency tends to add an additional layer of inefficiency costs derived from misalignments with comparative advantages.

The conflict between “self-sufficiency” and “energy security” is best illustrated with the case of corn-based ethanol in the United States. Domestic demand for ethanol has boomed in recent years, due not only to higher crude oil prices but also because the Energy Bill of 2005 introduced a Renewable Fuel Standard (RFS) that mandates a specific level of biofuel use, which is to be fulfilled primarily with ethanol. Unlike other countries that mandate content as a percentage fuel blend, the U.S. law sets a quantitative volume target and the required volume will rise from 4.0 billion gallons in 2006 to 7.5 billion gallons in 2012. Further, the replacement of MTBE (Methyl Tertiary Butyl Ether) with ethanol as an additive in refining has also contributed to a demand surge for the latter (Figure 3). [3] President Bush’s State of the Union address last month has spurred that demand prospect by proposing a cut of the US petrol consumption by 20% in ten years, reducing American dependence on imported energy, part of which would come from ramping up the use of fuels such as ethanol and biodiesel.

The bulk of the augmented demand for ethanol in the US has been covered by domestic production, which increased from 1.63 billion gallons a year (bbg/y) in 2000 to 5.4 bbg/y forecast for 2007. [4] The number of plants producing corn-based ethanol has increased from 54 in 2000 to 113 in 2007, while 78 other plants are under construction.

The share of corn output used for ethanol production went up from 14% in 2005 to 20% in 2006. As increases in both planted area and yields have not been enough to accommodate the huge additional demand, corn prices have moved up from US$2.30 a bushel in September to a record high US$3.85 in December last year.

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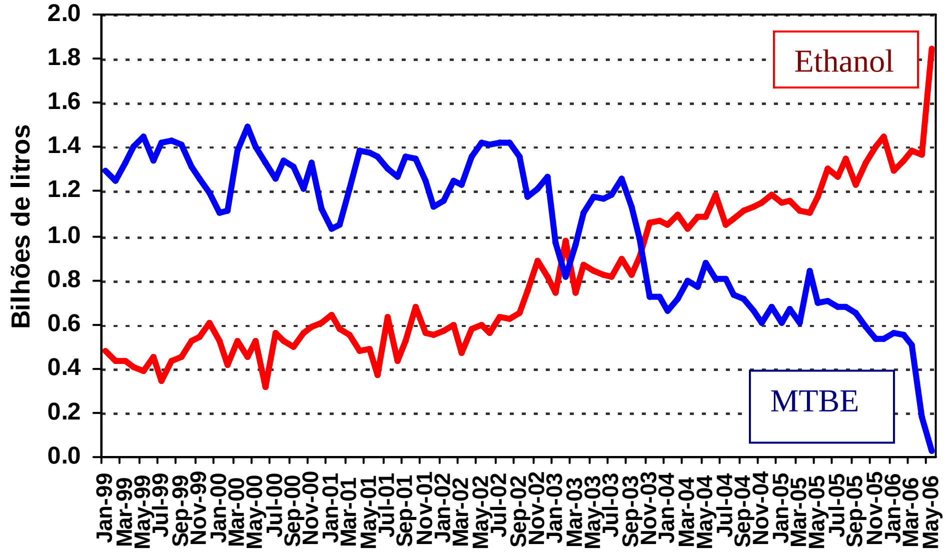
[3] MTBE is a groundwater contaminant and potential carcinogen and on May 5, 2006, liability protection for MTBE-related lawsuits expired. This has led many U.S. states that had not already phased out MTBE to take action.

[4] These and the following figures have been obtained from Hester (2007).

FIGURE 3

US CONSUMPTION OF ETHANOL AND MTBE




Source: ICONE (www.icone.com.br)

This evolution happened as ethanol was rising from 1.2% of total gasoline demand in 2000 to 3.5% in 2006 in the US. One can only wonder how significant might turn out to be the impact on prices of corn and ethanol, as well as crowding-out effects on other domestic agricultural outputs, if that percentage of ethanol were to rise to much higher levels in the near future on the basis solely of local production. Autarky in this case runs against both energy security and food security.

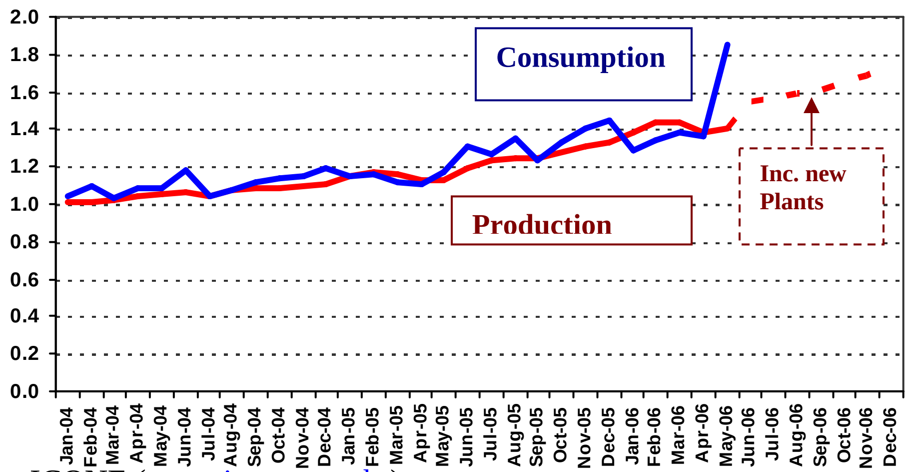
In fact, as shown in Figure 4, the additional demand for ethanol has already exceeded current production and the gap will remain even taking into account the mid-term projected production capacity. Despite the presence of steep tariffs, US ethanol imports have boomed and domestic price hikes of ethanol and corn would have been more accentuated had it not been for purchases from abroad. Imports are also favored by the location of most of the ethanol plants in the Midwestern US, without a cheap transport infrastructure to carry their product to the energy demanding East and West Coasts.

Limits of land availability and the ensuing pressure on other agriculture outputs as a result of increases in the use of biofuels may also of course apply in a context of open and interdependent economies if a move toward biofuels reaches a world scale. But it is worth noting the widespread presence of idle land in many parts of the developing world, which makes the possibility of a trade-off between energy and food security in the case of biofuels something less likely to be stringent at the global level.

For the sake of illustration, let us consider the case of Brazil, where sugar-cane-based ethanol already accounts for more than 40% of the gasoline pool and the cost of ethanol was hovering around US$0.83 per gallon last year, as compared to US$1.09 per gallon in the case of the US corn-based ethanol (Nastari, 2006a). Only 2% of Brazil's arable land (6 million hectares) is currently employed for producing sugar cane, while the area usable for that type of culture can reach at least 12% (Itau Corretora, 2006) (Macedo, 2005). Brazil still has 106 million hectares of land available for agriculture (without touching on forest areas), or 13% of all territory (Bear Sterns, 2006).

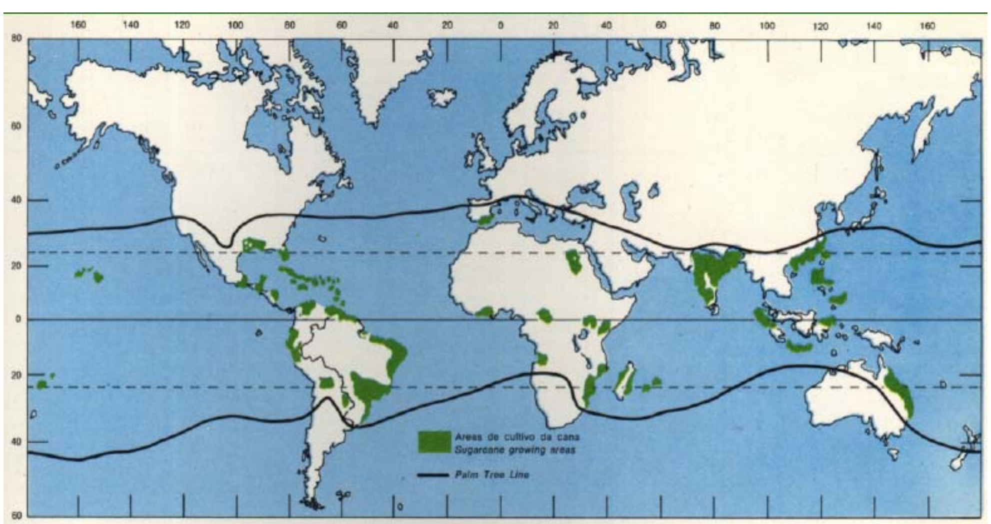
"Given that the world consumption of gasoline is currently a little over 20 million barrels/day, assuming the same efficiencies seen in Brazil today, 19.9 million hectares of sugar cane would be required to produce 2 million barrels/day of ethanol, and substitute 10% of all gasoline consumed in the world. This land mass is available in many regions: in Brazil, in Central and South America, in Africa and in Southeast Asia." (Nastari, 2006a: p.4). As illustrated in Figure 5, there are many other areas with a high potential to produce sugar cane ethanol and cater to the US market, as long as an appropriate definition of energy security is applied by the latter.

**FIGURE 4 - US PRODUCTION AND CONSUMPTION OF ETHANOL**




Source: ICONE (www.icone.com.br)

**FIGURE 5 - SUGAR CANE GROWING AREAS**




Source: Embrapa

## 2. Environmental concern as a driver toward use of biofuels for transport

Environmental concerns at both local (pollution in cities) and global (carbon dioxides emitted toward the atmosphere) levels associated with the consumption of fossil fuels have also generated interest in biofuels. These are cleaner than traditional fuels at local city levels – as in São Paulo, where data already collected has made evident that air quality is positively correlated with the use of ethanol. Furthermore, incorporating biofuels into the transport fuel pool is bound to diminish overall greenhouse gas emissions. In fact, as the International Energy Agency has stressed, the use of biofuels is one of the very few means of greening the transport sector available and already tried.

We must concede that there is a fierce controversy about the efficiency of biofuels in terms of mitigating carbon emissions, environmental impacts, and use of resources. On the other hand, viewpoints on the energy efficiency and lifecycle of biofuels diverge mainly as a result of different methodologies employed as well as of frequent biases in samples used as a reference.

Some argue that the total energy consumption involved in the production of ethanol from cereals is more than twice that used to make petroleum gasoline. Most of the counter-arguments against ethanol use come from the US, where ethanol is produced in a temperate climate largely from corn and grains: the major one is that intensive agricultural practices utilized in the US corn belt produce ethanol that requires heavy energy inputs in the form of fertilizers, herbicides, irrigation and transportation and many ethanol producers use coal-fired power generation. [5]

In other regions of the world, reference is often made to the possible intensive use of scarce water for irrigation. This is the case of northern China, across India and the western corn/soy belt in the US (WorldWatch Institute, 2006).

At this point, it may be worth recalling how differentiated the features of ethanol-producing crops are and thus why the environment-related driver toward biofuels is well grounded provided that more efficient crops are allowed to grow in a context of internationally integrated markets.

Steps of ethanol production include: "(1) in the case of starchy or cellulosic feedstock only, a preliminary saccharification process is required to convert starches and more complex carbohydrates into water-soluble sugars; (2) fermentation of the sugars into ethanol; (3) distillation of the resulting "beer", yielding hydrous ethanol; and (4) dehydration of the final liquid to separate the 5% water content, resulting in anhydrous ethanol" (Hodes et al, 2004, p.4).

The economics of ethanol production is very location-specific, but sugar-bearing crops carry at least two sources of important advantages over alternative feedstock materials. First of all, sugar carbohydrates are already in a fermentable form, unlike those

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**5** Hill et al (2006) report a life-cycle accounting to assess ethanol from corn and biodiesel from soybeans, whereas Pimentel & Patzek (2005) approach corn, switchgrass, wood, soybean and sunflower. See also Wallen (2006) for a review of the controversy.

in starches and cellulosic materials, thereby obviating that preliminary saccharification or hydrolysis step. These additional steps in the cases of starches and cellulosic materials imply higher capital needs and operating costs and tip the net energy balance in the case of non-sugar-bearing crops. [6] Secondly, the residues of the sugar-bearing feedstock are often sufficient to meet on-site heat and power requirements. In fact, some Brazilian ethanol producers are net suppliers to the electricity grid.

In Brazil, there is a large number of annexed distilleries (instead of stand-alone, autonomous distilleries), i.e. dual plants producing both sugar and ethanol. The dual plants provide two sources of advantages: **(**i**)** distilleries can profit from effective utilization of the waste or by-products of sugar manufacturing – *molasses*, which serves as an additional raw material for ethanol production, and *bagasse*, which can be used for on-site energy requirements [7] - as well as (ii) production flexibility, thereby mitigating producers' risk stemming from shocks and fluctuations in the demand for all of the various final products. Dual plants producing both sugar and ethanol can switch easily between both depending on relative prices (even if that switch between ethanol and sugar in these dual plants is restricted to a maximum of 60 percent in either direction under current technologies). Such a diversification gain constitutes a hedge against price fluctuations and enhances the economic value of sugar cane ethanol production.

Regarding water intensity, one must take note of the existence in Brazil of over 500 cane varieties, without the need for irrigation. Further, due to the fact that Brazilian cane has been genetically bred to yield more sugar throughout the years, the stalks are particularly weak, which makes them easy to break down, and ideal for converting to energy.

While the ethanol extracted from corn yields only about 15% to 20% more fuel than the fossil fuels that are used to produce it, in Brazil the sugar cane based ethanol yields about 830% more. This is due not only to favorable soil and climate conditions but also to years spent in perfecting suitable varieties of cane and even genetically engineering them to optimize yields. Transport is minimized when ethanol plants are built next to the sugar cane fields, as is always the case in tropical countries. Herbicides are not needed in cane fields; fertilizer inputs are left to a minimum by recycling the waste from ethanol distillation (*vinasse*) after drying it; and the drying, as well as the entire operation of the mill, can be powered by a mini-power plant burning the cane stalks after extracting the juice.

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**6** Brazilian flex-fuel (ethanol/gasoline) and ethanol-only cars run on hydrous ethanol, making possible also the suppression of the last stage of ethanol production.

**7** "*Molasses* is produced sequentially in three grades (A, B, and C) during cane juice processing, with sugar content declining by grade. *Bagasse*, the fibrous by-product from the crushing and milling of cane or sweet sorghum (or the leftover tissue from the sugar cane stalks), provides a low-cost, reliable on-site energy source for process heat and electric power production. Indeed, the processes are highly complementary; steam and waste heat from bagasse combustion can be highly efficient if used for ethanol distillation and dehydration processes, as well as for heat and power in sugar production" (Hodes et al, 2004).

Energy output-input ratios and efficiency in use of resources are also favorable in several cases of biodiesel crops, such as palm oil, castor oil and jatropha (WorldWatch Institute, 2006). Malaysia, Thailand, Indonesia and others are expected to expand substantially crops like those in the near future.

As far as greenhouse gas reduction is concerned, costs per ton of GHG reduction also display a wide dispersion depending on the source of the biofuel (WorldWatch Institute, 2006). Sugar cane has the lowest cost per ton of CO2 reduction from any feedstock source, reaching around US$50 per ton of CO2 equivalent greenhouse gas emissions, in comparison with almost US$600 for corn.

The conclusion is straightforward: the misperceived inefficiency attributed in general to biofuels in terms of mitigating carbon emissions, environmental impacts, and use of resources derives from inadequate samples of crops and geographical locations taken as a reference. Whenever sugar cane and some new biodiesel crops typical of tropical areas are considered, as well as a scenario with full cross-border integration of agroenergy national markets, it becomes possible to understand why many have believed biofuels for transportation to be a promising way to partially reduce the environmental damage associated with fossil fuels.

Biofuels may act as a partial substitute to fossil fuels and gradually increase their participation. It is possible to obtain granularity in the evolution of demand and supply either with the use of flex-fuel vehicles and/or varying possibilities of (mandatory or voluntary) blending. It is not a matter of binary choice - either fossil fuels or biofuels - , certainly not at the aggregate level and not even for the individual user.

After all, the challenge is daunting in the case of diversifying out of fossil fuels for transports, an increasing source of demand in the following years according to IEA projections. Private cars almost tripled in China along the last 10 years, augmenting from 6.25 million to 17 million, while India had 1.2 million in 2005 and a fleet growth forecast at 10% per annum. All projections of demand for fossil fuels from civil aviation point to the same direction. [8]

Regarding clean energy and mitigation of climate change the fact is that a “menu approach” will have to be adopted (World Bank, 2006). Given the heterogeneity of geographies and the unavoidable uncertainty associated with every technological path currently pursued, we will have to proceed along several routes, with a portfolio approach applied on a country-by-country base. Yet the fact is that biofuels seem to face no other feasible competitor as a substitute for fossil fuels in transport in the near future.

Should we wait for other technological breakthroughs before we pursue the route of biofuels for transport? How about hydrogen fuel cells in automobiles and cellulosic ethanol?

[8] Embraer had in mid-2005 a 2-year backlog list to convert aircraft engines from gasoline to ethanol, and it was then looking into converting the T25, a military-training turbojet, to ethanol (Theil, 2005). Ethanol-fuelled small planes for farm use developed by Embraer and Aeroálcool are undergoing certification.

In the case of hydrogen, it is worth noticing that new and much more complex technologies would require a reinvention of automobiles, making any transition harder and longer. In fact, alcohols are the fuels with the largest hydrogen content (after health-hazardous methanol) (Theil, 2005).

Another possibility of a leap is to move beyond ethanol from sugar cane, and biodiesel, toward cellulosic ethanol produced from wood pulp and bio-wastes with the aid of new cocktails of digestive enzymes. Provided that the first phase of all non-sugar-cane ethanol production ceases to be very costly, as it still is in the current cellulosic-related technologies, that experimental front of biofuels will carry most promise. Theoretically ethanol could be extracted from almost anything from switchgrass to scrap paper.

“The next generation of biofuels may be easier for northern countries to produce economically. Instead of getting fuel from sugar or oil - a tiny part of the total plant - upstart companies are building new factories that convert a plant's entire ‘biomass’ into fuel. Present fermentation technology leaves the cellulose - a stiff material that gives plants their structure - as waste. (In the case of biodiesel, oil is pressed from the seeds; the rest of the plant is discarded.)” (Theil, 2005, p.3). A commercial plant designed to take leftover straw from surrounding farms and turn it into ethanol was opened in Canada in 2004 (by Iogen). The key innovation is to use genetically engineered enzymes – which are still available only at high expense – able to convert into glucose the cellulose contained in straw; the glucose is then fermented to produce ethanol. In fact, biologically obtained enzymes can break down virtually any plant fiber into a final ethanol output, but so far a shortcoming has been the lack of capacity to produce those enzymes cheaply on a large scale. Doubts remain only about how long it is going to take to overcome this hindrance.

However, the cellulosic ethanol may not be the end of the sugar cane hegemony. Using waste bagasse at sugar cane mills could double their ethanol yields; with harvesting of currently discarded leaves and tips, ethanol yields could even triple (WorldWatch Institute, 2006). Efficiency considerations suggest that cellulosic ethanol would hold greater promise if developed using sugar cane feedstock in Brazil, instead of distilling citrus pulp, yard waste, peanut shells and other natural waste or switchgrass, hybrid willow, hybrid poplar or others.

Technology evolution is unavoidably plagued with uncertainty and time to transit out of fossil fuels will be at the essence as far as environmental issues are concerned. Ethanol and biodiesels have already accumulated some experience. Further, any evolution toward post-conventional biofuels would benefit from an intermediate stage with the latter – among other reasons, because the infrastructure of distribution would be same, as well as because the eventual overhaul of the production structure will likely occur on an incremental basis. Thus, it does not make sense to put the current biofuels agenda on hold until other technological breakthroughs happen.

## 3. Development as a driver toward biofuels

Economic analysis usually assumes the economy works at the efficiency frontier when calculating “opportunity costs”. Nonetheless it may not be hard to accept the evidence that in reality many developing countries often present unused or unproductively used labor and natural resources. As an example, China’s and East Asia’s extraordinary growth can be partially explained by the transfer of people from unproductive occupations in rural areas to manufacturing activities.

In parts of Africa, idle natural resources as such should be accounted for with zero opportunity costs in any economic evaluation. In the case of biofuels, these should be assessed not only vis-à-vis oil prices but also taking into account potential environmental gains (including renewability and carbon cleanness at the world energy matrix level), energy security at the international level associated to diversity, economic aspects (incorporation of natural resources and occupational shifts), and local social aspects. [9]

Backward and forward linkages could be sparked in the context of a biofuels-led export-oriented agroindustrial development (Hodes et al, 2004), which is to be compared with the current over-reliance of many Sub-Saharan countries on exports of minerals and fossil fuels. And benefits from a biofuels-led agroindustrial development would go beyond the alleviation of foreign-exchange constraints and those backward-forward linkages, as they would include the phasing-out of local consumption of fossil fuels. Rising crude oil prices have more than cancelled out the theoretical benefits of the recent Multilateral Debt Relief Initiative: Sub-Saharan African nations are projected to save roughly US$1 billion a year from the most recent debt forgiveness while the International Energy Agency calculates that the higher oil prices prevailing in the last few years have cost the region an additional US$10.5 billion a year in oil imports (WorldWatch, 2006). Therefore, oil import substitution with locally produced biofuels, as long as done without incurring in high inefficiency would also add a domestic gain to the export push.

In order to make a case for biofuels as an outlet for using idle resources and sparking growth in developing countries, however, we have to address two other questions: (a) given current techniques and production conditions, does ethanol require, in order to remain competitive, oil prices to stay at the levels prevailing in the last few years? (b) Is it true that only in Brazil it is viable to produce ethanol on a competitive basis? The answer to both questions needs to be “no” or otherwise scarce local resources would have to be diverted from other needs to sustain biofuels production for a considerable time.

In the case of Brazilian ethanol, the oil price threshold of competitiveness without subsidies or strong exchange-rate deviations from Purchasing Power Parity (PPP) is estimated to lie in the range of oil prices at US$35 to US$50 per barrel (Nastari, 2006a) (Macedo, 2005). The cost of producing ethanol in Brazil stands at US$0.23-25 per liter or US$0.87-0.95 per gallon.

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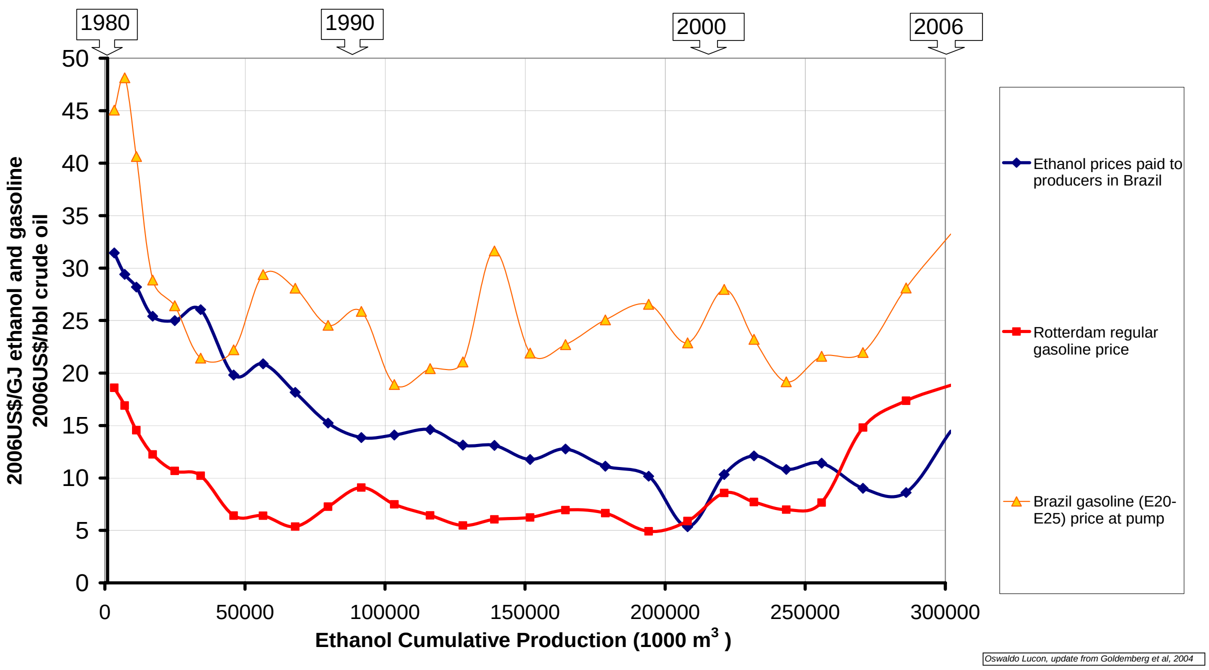
**9** In Brazil, a strategy of producing biodiesel from castor oil grown up in degraded and arid areas of the Northeast, a poor region, has been set up and several favorable social impacts are expected.

This is the outcome of a learning curve crossed along the last decades as shown in Figure 6. The cumulative experience with production allowed for an evolutionary trajectory of improvements at the agricultural, manufacturing and distribution sides, whereas the mature technology of oil production seems to have exhausted its opportunities for cost improvement.

**FIGURE 6 – BRAZILIAN ETHANOL LEARNING CURVE**




Source: Goldemberg (2006).

Another factor of attractiveness for using ethanol has been the emergence of flexible-fuel vehicles, capable of running – without the need of any mechanical adjustment - on any combination of ethanol and gasoline. The additional engine device responsible for reading the fuel content costs about US$100. Besides creating an economic value of diversity and hedging for consumers, and thus reducing the long-term commitment involved in the day-to-day option for ethanol, it facilitates cross-fuel arbitrage and enhances the scope for mutual price communication between the ethanol and gasoline retail markets. By combining hybrid mill-distillery complexes in production and flex-fuel vehicles in usage, both producers and consumers obtain hedge against price volatility.

One factor often alluded to as a threat to regularity in sugar cane ethanol supply is a particular variant of the tradeoff between energy security and food security that we have addressed: the "sugar price argument". While oil faces a single world demand, ethanol meets with double or competing demands. Sugar production may compete with ethanol as an end-product of sugar cane harvests – as it happened in Brazil in the 1980s (Sandalow, 2006). In fact, the competition between sugar and ethanol occurs on a daily basis, as the dual plants can produce either one or the other "at the flick of a switch, depending on the world price of each" (Mathews, 2006, p. 5). [10] Thus, the floor of oil prices necessary to bring ethanol supply forth might rise during periods of expensive sugar, because of the competition between sugar and ethanol on the production side.

Not by chance, sugar prices started hiking substantially once the current ethanol boom established its course. In the beginning of August 2006, sugar prices were 42% higher than a year before and 67.4% higher than 2 years before. So much of Brazil's sugar cane was then being used for ethanol that the world sugar price reached a 24-year high of more than 19 cents a pound. Interestingly enough, there was no correlation between prices of sugar and oil in the nineties (correlation of 0.01 between 1989 and 1999), whereas that correlation rose to 0.7 during 2000-2006 (Nastari, 2006b).

However, one has a flexible price-sensitivity in the supply of both sugar cane-based ethanol and sugar (as compared to oil production) and there is no reason why sugar demand should rise systematically faster than the oil demand, or to believe that sugar demand is structurally so prone to temporary shocks to be a major source of short-term disruptions in the ethanol market. The recent surge of sugar prices has come as the immediate result of an adjustment to greater use of ethanol rather than a cause: the above-mentioned correlation implies no causation. Again, as long as enough arable land is integrated in the global market and there is full financial and trade integration in the international economy, occasional sugar price booms will not jeopardize the use of ethanol as a substitute for fossil fuels. Ultimately, there is no severe tradeoff between energy security and food security regarding the use of biofuels if a truly global market is in place.

Now we come to the question of whether the competitive production of ethanol is only viable in Brazil or whether the Brazilian experience with biofuels can be creatively replicated. In the specific case of ethanol, it is true that no country can currently produce ethanol from sugar cane as cheaply as Brazil. But many come close - including Australia, India and many of the tropical countries in Africa. And with some technological assistance from abroad an "ethanol zone" covering Brazil and other Latin American and Caribbean economies, India and South-East Asia and Africa could be created so as to guarantee the operation of a geographically diversified supply network. Similar networks can also be formed in the case of successful biodiesel experiences.

Knowledge-intensiveness and creative absorption of technology have been at the heart of the Brazilian experience since the launching of Proalcool in 1975 (Mathews, 2006). Processes of local learning-by-doing and learning-by-using were central with respect to, e.g., the accumulation of managerial skills and agricultural research. Each mill uses on average about 15 varieties of cane – more than 500 varieties are present at the

[10] Some of the new plants in Brazil are triple-integrated, working with sugar, ethanol and biodiesel, and with a multi-feedstock biodiesel process (Mathews, 2006, p. 5).

country level – and there is a constant development of new commercial varieties. Every phase in the ethanol production process – from planting to harvesting to ethanol plant processing – is optimized wuth the use of advanced modeling techniques and information technology.

But there is at least a partial transferability of technology and managerial capabilities as the Brazilian local development was not totally idiosyncratic and some of the outcomes are readily usable in other contexts, even allowing in some cases for advantages of latecomers. For instance:

(i) car motors available embodying a cumulative learning about corrosion of motors and world automakers that know how to use modified materials that resist breakdown;

(ii) flex-fuel devices that read automatically when a new fuel is present in the tank and whether the mixture of oxygen is too rich or too lean;

(iii) cars with a little back-up gas tank under the hood that helps starting in cold weather;

(iv) a know-how about improving yields by adapting seeds, equipments and satellite imagery techniques to specific local conditions;

(v) a long list of policy mistakes to be avoided (Sandalow, 2006); etc.

Brazil's development of ethanol is in itself a successful story of South-South cross-fertilization, from the sugar cane plant itself to ethanol making and end uses. In the beginning of the ethanol program in the 70s, a R&D unit at Coopersucar – then leading the process at the private sector - sprang from a one-year mission of a dozen Brazilians sent to Mauritius to learn sugar and ethanol production. Also key to the technologies locally developed in Brazil were capital goods and consultants from South Africa. There is no reason why a reverse process of transfer and creative adaptation of technology – from Brazil outwards - cannot take place.

## 4. A triple dividend from biofuels

The bottomline of our analysis comes in a straightforward manner: there is a high likelihood that currently misused resources and areas in developing countries can be made efficient and competitive in producing biofuels, as long as appropriate access to markets, finance and technology abroad is given. Widespread biofuels production and use would generate development and, by doing so, would further enlarge world gains in terms of both energy security and environmental protection.

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