1. INTRODUCTION

This paper starts with an historical description of the major uses of biomass for energy in Brazil (Section 2) as well as the policies already set to promote the use of renewables, in particular biomass (Section 3). Section 4 discuss the potential for production of biomass, while Section 5 presents why the potential may never be achieved; barriers for such development are mentioned with the propose to call attention of decision-makers on necessary policies to be further implemented. Section 6 discuss the still existing technological gap that essentially is another barrier for the large use of renewables as an energy source. Section 7 presents the conclusions (see Figure 1).

2. PAST AND PRESENT USES OF BIOMASS FOR ENERGY

Brazil has a very clean energy matrix as shown in Figure 2. In 1970 almost 60% of the total energy used in the country was renewable and even in 1999 the share is higher than 40%. Major contributors to the energy matrix are hydro, wood and sugarcane. Due the large contribution of hydroelectricity in power generation (more than 90% during 1970 – 1999), and the significant amount of energy used as electricity the accountability of its contribution to the energy matrix can yield different results. One way for accounting hydroelectricity is to assume that each kWh has 3595kJ. Another way, considers the amount of primary energy from fossil sources that would be needed to use to generate 1kWh, if thermo conversion technology is used. Under this latter approach the amount of kJ to be associated with 1kWh depends on the thermodynamic efficiency obtained with existing thermal generators. Presently, modern combined cycle systems have efficiency near 60% and under good operational conditions average efficiency may surpass 50%. Nevertheless, in Brazil, average thermoelectricity efficiency was around 28% up to the year 2000, when new gas-fired units started to be completed. Present average efficiency for all the thermoelectric system does not account for these new units but up to the moment they contribute with a small share of all thermoelectricity produced and some of them are operating as single–cycle initially. This means that a reasonable guess for present conversion efficiency is 30%, or 1kWh is equivalent to 11982 kJ.

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Figure 2 was constructed assuming 1kWh = 3595 kJ, and if the conversion rate is taken as 11982kJ applied to more than 350 TWh/year the amount of equivalent thermal energy would be $4.19 \times 10^{11}$ MJ/yr. Considering an average daily consumption of oil + natural gas of 2 million barrel, the amount of energy derived from such fossil resources is $4.36 \times 10^{11}$ MJ/yr, or almost the same contribution than hydro. Considering that sources other than biomass, natural gas, oil and hydro contribute with less than 10% of the total it is possible to conclude that hydro participation, instead of 18% share as shown in Figure 1, should contribute with around 30%. Actually, the number obtained from the National Energy Balance (MME, 2000) is 34%.

Under this new accounting renewables represents 58% (34 + 24) of all energy used and also, due the significant increase in hydroelectricity consumption and the declining share of renewables during the period 1970-1999, its share in the energy matrix has been kept essentially constant. For Brazil the different accountings are so significant that yields different conclusions. We do recommend that the last form of accounting be used since it is more realistic. Obviously, the very low efficiency of thermo generation (30%) will improve with the introduction of several new and efficient natural gas based electricity generation, but even for a future achievable efficiency of 50%, renewables will continue to represent a large share of the country energy consumption.

From Figure 2 it is visible that wood, essentially firewood, has become less important, while sugarcane participation increased significantly between 1979 and 1988, and has remained stable since then. Firewood declined essentially due the large use of LPG in households, and a decline on the use of charcoal in the pig iron industries. Figure 3 shows such trends and a decline on the absolute amount of firewood use in the agricultural sector, is observed, while for industry an absolute growth occurred between 1981 and 1987, due the oil crises, and after that has remained stable. Figure 4 shows that absolute amount of biomass has been quite stable in the 90s, while total firewood consumption declined and sugarcane increased.

Figure 5 forecasts electricity production up to the year 2010 and it is visible the increasing participation of thermoelectricity. Hydroelectricity is also expected to increase, but at a modest rate compared with the relative growth observed in the 70s, 80s and 90s.

Figure 6 displays part of a recent survey carried out in Brazil by the CENBIO – Brazilian Biomass Reference Center– to identify availability of agricultural residues. Figure 7 displays the aggregated results for the residues; corn, followed by soy, rice and coconut are the most important. Figure 8 shows the maximum amount of electricity that could be produced using these residues to power steam turbines (low or medium size units) with the present available technology, as well as using commercially available biomass gasifiers coupled with diesel engines. Near 120,000 TWh/yr could be produced if all these residues were collected and used for such purpose. Actually, most of these residues have no use today and are just burned. To provide a reference it is worthwhile to note that total electricity generation by 1999 was 350,000GWh.

Figure 9 displays CENBIO’s results for sugarcane harvested in the year 2000. Based on the amount of bagasse available, Figure 10 shows the total amount of electricity that could be
generated for 3 different technologies. Using 40-60 bars boilers it should be possible to generate 30,000 GWh/yr, while the largest figure 60,000 GWh/yr requires 80 bars boilers and steam savings in the sugar/ethanol mills. Figure 11 shows the significant interest for the use of bagasse in cogeneration units assembled in sugar mills. Around 190 GWh was sold to the grid in 1999 and the figures for 2000 and 2001 are expected to be higher. At this point it is important to say that modern technologies, converting biomass in clean gas form are being tested and if successful, when coupled with gas turbines, may yield up to 600 kWh/tonne of sugarcane processed (see Figure 33). This is 3 times the best result displayed in Figure 10.

Figure 12 displays CENBIO’s results for the availability of saw mills residues in different states and region of Brazil. In Figure 13 we see that more than 5,000 GWh/yr could be generated using large size units.

Figure 14 has results for the plantation areas in several countries, for oil crops. As observed around 250Mha of land is used in the world for this activity and major producers are USA, India, China, Brazil, Argentina and Indonesia. Almost all of these oil are produced for food purpose and Figure 15 has results for the yield of these crops in several countries. Average world yield is around 500kg/ha, which means that total oil production is 120 million tonnes or around 130 million m$^3$ (see Figure 15). Such figures are large for food purpose, but if the target is to use vegetable oil as a source of energy this amount is quite small. Probably, using all this oil in diesel engines it should be possible to displace 110 million m$^3$ of diesel (695 million barrels/yr or 2 million barrel/day, which represents 2.8% of total oil used in 2000). This results should not be considered as a conclusion against the potential of vegetable oils be used as an alternative fuels. On the other way, Figure 15 allows us to derive a different conclusion. As noted, average yield of oil crops varies from country to country and for Costa Rica, Honduras and Malaysia the yield is more than 4000 kg/ha. This happens because most of the world area used for oil crops plantation is dedicated for varieties that produces low amount of oil but have high value as food or have valuable co-products. as food or fodder. In some tropical countries, most of the planted oil crops have high yield of oil, as the case of palm oil. Assuming that oil crops for energy will have yield 10 times larger than the present world average, we can conclude that it should possible to produce 20 million barrels/day using 250Mha, or 2 million barrels/day using only 25Mha. Since such high-yield crops are not yet explored for fuel use it is quite possible to assume that in the future, if interest for such source of energy keeps growing, yields of 10,000 l/ha can be obtained, making vegetable oil use for energy more feasible.

Figure 16 shows average yield of planted forests in Brazil. Fast growing trees (Eucalyptus and Pinus) are extensively used for firewood and by the pulp and paper industries, respectively, while round wood (Acacia, Araucaria, others) are used for durable products. The pulp and paper industry is the largest user of Pinus, while the charcoal industry is the major industrial user of Eucalyptus. For the pulp and paper industry, Figure 17 shows the amount of installed power in 1997 an the forecast for 2003. It is worthwhile to consider that 1/3 of the present installed power is from small hydro sources, while 2/3 is based in the use of wood residues and black liquor. Some studies concluded that it should be possible to produce 2 times more electricity than is shown in Figure 17, by 2003, using higher pressure boilers and improving trees residues collection.
Figure 18 shows consumption of ethanol since 1974 up to 1999. The Alcohol Program started in 1975 proposing blend of ethanol in gasoline. By 1979 the amount of ethanol produced has increased so much that it became possible to use neat ethanol as a fuel for cars. This is the reason for production of two ethanol products: hydrated and anhydrous. Hydrated, which is 94% by volume ethanol and 6% water is used in neat ethanol engines. Anhydrous, which is 99.9% ethanol is blended with gasoline. Figure 19 displays the same information for the 1990 – 2001 period. Figure 20 displays the amount of total ethanol produced from the beginning of the Alcohol Program up to 1997, compared with gasoline and diesel. It is quite interesting to observe that between 1985 and 1992 both kinds of ethanol consumption surpassed gasoline, and both together surpassed diesel consumption since 1983 up to 1999. The reason for that is shown in Figure 21. Neat ethanol car production during 1984 – 1987 represented more than 90% of all new cars produced. By 1989 a serious shortage of ethanol occurred and this triggered the lack of interest in such kind of vehicles. Figure 22 displays the decreasing share of hydrated ethanol consumption due the significant reduction in neat ethanol car production after 1990. The number of neat ethanol cars declined quickly, to almost zero by 1996. Nevertheless their production never stopped and Figure 23 shows the monthly production of such cars in the period 1999 – 2001. Production is steadily raising from less than 250 units/month to almost 4000 by the end of 2001. More relevant is to examine the trend, which shows an increase. The reason for this increase will be discussed later on, but it is essentially explained by the lower cost of ethanol fuel compared with gasoline.

Figures 24 and 25 show results from two possible scenarios of ethanol consumption up to 2010. Scenario 1 assumes that neat ethanol cars production will continue at around 10,000 units per year for all these coming years. As a consequence neat ethanol cars in operation will be almost zeroed by 2010 due to the retirement of the old fleet. The 2010 fleet will be essentially composed by gasoline cars. Considering the historical increase in the numbers of cars sold, ethanol consumption will remain essentially stable and around 11-12 million m$^3$/year. Scenario 2 assumes a small retake in the production of neat ethanol cars. Under this scenario total ethanol consumption will remain around 12 million m$^3$, increasing slowly to a little over 13 million m$^3$ by 2010.

3. POLICIES – PRESENT SITUATION

Apart of ethanol, policies for renewable energy sources were absent up to 1998. With the privatization of the electric sector and the establishment of a new Federal Agency to deal with electricity some legislations were introduced. Figure 26 shows some major regulations that were designed to help renewables, including small hydro sources (SHS). The most relevant are Resolution 21/2000, which recognizes as cogenerator a facility that provides 5% energy economy as compared with separate production of the two form of energy, when using renewable sources of energy. When using fossil energy the economy must be 15% or more. This preference for renewables is useful because being a labeled as cogenerator implies in some economic advantages. Resolution 282/1999 was set in favor of SHS. It states that electricity from such source could use the existing grid system to be distributed to users, paying only 50% for the wheeling tool. Later on, the discount was
increased to 100%. This regulation opens a possibility for other renewables to claim equal rights. Another important policy was the establishment of different reference values for electricity generated from renewables. The reference value is the maximum value that a utility is allowed to transfer to the final tariff if they buy such kind of electricity from other producers. Values shown in the Figures are for the year 2001 and they are corrected annually to account for inflation or scarcity of electricity. Another important measure was set by Resolution 245/99. It states that the money addressed to constitute the CCC fund (a fund to cover the higher cost of thermal generation as compared with hydro, and built through collection of money from all electricity consumers) could be also used to finance construction of renewable based electricity plants. The Resolution was useful because not only makes money available, but this money has a lower cost than other financing sources.

Further regulation are shown on Figure 27. They state:

- New cogeneration plants may apply to the Regulatory Agency at any time for operational license and such request is analyzed using fast track mechanism.
- Natural gas will be always available for cogenerators, provide they request the fuel.
- For SHS even more advantages are set.

Figure 28 shows more recent regulations set for the use of ethanol. By the begin of 1997 a complete price deregulation was applied for anhydrous ethanol. By the end of 1997 tests were authorized for use of blended ethanol in diesel oil (3% and 10% latter on). By the begin of 1998, due the large surplus of ethanol, it was authorized to increase ethanol share in gasoline to 24%, from the earlier value of 22%. By the middle of 1998 hydrated ethanol price was deregulated. By the end of 1998 the Federal Government required that all new cars acquired for its own use should use neat ethanol, provided the model is available in the market. Also by the end of 1998, a regulation oblige the oil company PETROBRAS to stop sales of MTBE in the country. From these regulations, the ones setting free market price for both types of ethanol helped the sector to improve its efficiency. The one requiring a green fleet owned by the Fereral Government was poorly effective since auto makers buil only a few models using neat ethanol, and most of them are constructed under request of the future owner. Elimination of MTBE increased the anhydrous ethanol market.

It is evident that some isolated policies are occurring to help the ethanol market but unfortunately, since the early 90s there is a shortage of policies for providing a future for ethanol fuel. Without a definition of the government the market is moving slowly and little investment in production of ethanol and neat ethanol cars is happening. Fortunately, the policies the important policies set long time ago regarding the compulsory blending of ethanol in gasoline and the compulsory availability of hydrated alcohol in all service station are still in effect. Nevertheless, with the reduction of the neat ethanol fleet, in a few years service stations may see no commercial interest in having a dual fuel system and may put pressure to change regulation.
4. PERSPECTIVES FOR THE FUTURE

Figure 29 shows harvested areas for some major crops in 4 countries and the world. It is useful to note that some crops like soy and maize use 30 million ha of land in USA and 11 million ha of land in Brazil. In India, rice plantation uses 40 million ha of land. At global level, wheat production uses the largest area with 235 million ha followed by rice (180 million ha), maize (160 million ha) and soybeans (80 millions ha). Also, note that sugarcane uses a relatively small area of 19 million ha in all countries. Figure 30 shows the amount of biomass harvested by major crops. It is worthwhile to note the large amount of sugarcane (1300 Mt/yr) and sugarcane plus barbojo (residues which are cut, and burned or left in the field in most of the plantations), which adds to 1700 Mt/yr, as compared with all cereals (2400 Mt/yr). This comparison is important, when we see from Figure 29 that only 19Mha is used for sugarcane, while all cereal plantations exceed 450Mha. This is an important observation and the conclusion is that it is possible to collect 24 times more biomass from sugarcane plantation than from the average cereal plantation per unit of land. Furthermore, it is important to remember that since the agricultural revolution cereals have improved their yield by more than 3 times due the intense R&D effort carried out. For sugarcane and other potential energy crops such effort has never occurred and increase in productivity has been very small. Thus the present figure of 24 times more yield for sugarcane than for cereals may increase in the future if energy crops become a large economic activity.

Based in such evidences and the results obtained from the sugarcane and ethanol sector in Brazil, Figure 31 shows the results of a potential program with the purpose to increase sugarcane use for fuel production planted area from the present 2.6Mha to 13.1Mha (that is the area presently used by soy crops in Brazil). The project also has the goal of:

a) achieving an annual average yield of 140 tonnes/ha for sugarcane by the year 2020 (twice the average figure for 2000)
b) extracting 100 l of anhydrous ethanol per tonne of sugarcane
c) using bagasse and barbojo as a source of electricity achieving an average production of 500 kWh/tonne of sugarcane processed.

Results for the year 2020 are very impressive. Using 13.1Mha of land it is possible to produce 2.4 million barrels per day of ethanol and generate 919 TWh/yr of electricity. Total energy production will increase from the 2001 value of 0.5 EJ (0.43 from ethanol - 0.064 from electricity); to 10.77 EJ(4.33 EJ from ethanol and 6.44 EJ from electricity). For comparison global oil demand is expected to be 68 million barrels per day and electricity 22.000 TWh/yr at 2020. This means that using 13.1Mha of land for sugarcane crop it is possible to produce 3.5% of all oil and 4.2% of all electricity required by the world by 2020. Figure 32 is useful to demonstrate that an average productivity of 140 tonnes/ha is a quite reasonable assumption. Today some countries have average productivity above 120 tonnes/ha/yr. Figure 33 shows how much electricity can be obtained from one tonne of sugarcane processed, using conventional and advanced technologies. Almost 600 kWh/tonne is possible. Figure 34 shows that 1400 GJ/year/ha is already obtainable from commercial sugarcane crops.
Figure 35 shows the results of the table presented in Figure 31 in graphic form. It is useful to note that more energy is produced in the form of electricity than as liquid fuel. Major conclusion is that electricity generation at the level of 919 TWh/year is too much for the demand of Brazil and surrounding countries. The same is true for 2.4 million barrels of ethanol by 2020, but liquid fuel can be exported and it is an assumption of this text that an international market for ethanol will be established soon. Considering that electricity cannot be exported to far away sites, the conclusion is that a share of bagasse and barbojo must be used for other energy forms (e.g. conversion to ethanol through hydrolysis of cellulosic material) or to non-energy uses (e.g. activated charcoal).

Considering the good results obtained in Brazil, Figure 36 shows a plausible scenario where the interest for sugarcane plantation expansion involves other countries. It is assumed that 143Mha could be used for sugarcane plantation by 2020. Figure 36 also shows the amount of ethanol and electricity produced using all this sugarcane.

Figure 37 presents a comparison between the amount of agricultural land available and how much is being used for arable and permanent crops, in 1999 for some countries and for the world. It is very clear that availability of land for growing 143Mha of sugarcane is not a problem provide selected countries are involved. It is clear that plants land is available in Brazil, China, USA, but little in India.

Nevertheless, sugarcane requires a tropical weather with some minimum amount of rainfall. This limits land availability in China and USA, but it should not be a problem to locate areas with an extension of 10 million ha in both countries. In this paper we did not search for a final answer to this limitation but our guess is quite reasonable considering the availability of around 250Mha and 400Mha of land in USA and China, respectively. Regarding Brazil and several other tropical countries (in Latin America and Africa) the land extension allocated for them should be easily obtained.

Figure 38, 39 and 40 are taken from a presentation curried out by Giuliano Grassi in the First World Biomass Energy Conference, hold in Europe, in 2000. The author presented some data about the amount of present production of sugar derived from sugarcane (2/3 of 216Mt/yr) which could yields 144Mt/yr of ethanol. Figure 39 is a view of the future where it is assumed that at an ethanol price of US$ 250/tonne it should be possible to create demand for 2000Mt/yr, from which 500Mt/yr will be obtainable from sugar/starch crops (this means mainly sugar cane and sweet sorghum, as well as maize). Such amount of ethanol could be used partially for the transportation sector (1450Mt/yr which represents 20% of present oil consumption) and the remaining for power and heat generation yielding 2000TWh/yr (50% conversion efficiency), which represents 15% of the present electricity market. The total amount of ethanol that may be produced represents 7.0 million barrels per day. This is 3 times less of this paper scenario (Figure 31), but shows that others studies had already considered large volume of ethanol production. Regarding the final user the author suggests that a share of ethanol could be used as fuel for combined heat and power generation, what may no be as efficient as using the bagasse and other residues, as

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3 The figures are slightly lower than the numbers presented by FAO, 2002. But for the purpose we are using them they are good enough.
proposed in our scenario (Figure 31), but considering distributed electricity supply is gaining market, it may be a reasonable guess.

Microturbines may produce electricity and heat with very high combined efficiency and ethanol at low price could be a feasible fuel, mainly if its supply is well distributed. The most important assumption of the author is for ethanol cost (US$ 250/tonne). As we will discuss latter on, this price has already been achieved in Brazil, without subsidies and without adding externalities. Figure 40 list the potential markets for ethanol use as forecasted by Giuliano Grassi.

5. BARRIERS

All the future results up to now have been presented based in technological and some economic feasibility. Unfortunately, the market potential for a product is much smaller than the technological and economic potential. Figure 41 displays, as an example, for C efficiency projects several different potentials and how they evolve with time. As shown, market potential (that represents what is commercially feasible) is lower than the economic potential due to market failures. Such market failures include lack of information, subsidies, and others, which restrict the use of a new technology even if its cost is better than the current technologies. Information dissemination costs money and subsidies are usually a routine in the oil sector. These subsidies are directly or indirectly available and it is very difficult to convince decision makers they should be extinguished. Also, benefits added by renewable energy (as is the case of ethanol) are not accounted as a real value of the new product. Such gains for the society are called externalities and when accounted usually increases the value of renewables, as compared with fossil energy. Another potential shown in Figure 41 is the socio-economic potential. To achieve that potential level of commercialization it is necessary to change habits and attitudes of the population, as well as, create new values. An example is the sales of green electricity. Some individuals already understand the necessity to protect the environment and thus accept to pay higher tariff for electricity generated from renewables. The technological potential is even bigger but high cost is a barrier to achieve it. And finally, we can try to increase the technological potential, approaching the theoretical limit by improving the knowledge, through R&D.

Figure 42 displays an important result that to be modified may require a change in social behavior. The plot shows CO₂ emission due the use of energy in the four end-use sectors. Past data is available and the results for 2000 onward are obtained assuming the future will be a continuation from the past (business as usual scenario). For the last 40 years the amount of fossil fuel used in the transportation sector (and consequently the amount of CO₂ emission) has increased at a rate of 2.4%/yr, independent of any effort to improve energy efficiency. On the other hand, industry has been able to reduce significantly the rate of fossil fuel use, as well as the building sector (households and commercial constructions).

Figure 43 and several following ones discuss the economic potential and market failures. It is shown the sugar price in several countries and how different they are even considering the existence of an international market. High prices are possible due subsidies that are commonly available for agricultural activities. To protect their own farmers OECD
countries use public money to overpay local sugar producers. Even in the same country subsidies are different for sugar produced from different crops, as is the case of USA where sugar from sugarbeet is sold at higher price than sugar from sugarcane.

Figure 44 deals with shortage of information, which inhibits market potential. It shows gasoline, anhydrous, hydrated ethanol price for 2001, in Brazil and the future market for ethanol as quoted in the exchange stock for the year 2002. The results for ethanol are very good, considering the limited supply available in 2000 and 2001. The very low price in 1999 and a very intense drought in 1999 decreased by 20% the sugarcane harvested by 2000 and 10% for 2001. Results for 2002 are much better and it is anticipated to return to the production level of 1999 (330 million tonnes of sugarcane harvested). This increase in production is pushing down future prices of sugar, and consequently, ethanol. A value of US$ 0.16 is expected for hydrated ethanol, assuming present exchange ratio will be in effect by the rest of the year 2002. At such prices, hydrated ethanol will cost less than gasoline produced from oil quoted at less than US$ 18/barrel as occurred in November/2001 (see Figure 43). Even considering that 25% more alcohol is required for a car to run the same distance when fueled by gasoline, hydrated ethanol would cost US$ 0.21 compared with US$ 0.19 that was the lowest cost of gasoline in 2001.

Figure 45 shows from one side that subsidies are not available for most of the ethanol produced in Brazil (some 15% of the total, produced in the Northeast region or in some other poor areas are subsidized for social reasons), while significant revenue is generated to the Federal and State governments through its commercialization. Figure 45, on the other hand, has valuable information regarding the final price. As observed hydrated ethanol price to the final user should be R$ 0.99/liter but this is much above the average price found in service stations (see Figure 46 and 47). Final fuel prices are determined by the market and they range from R$ 0.70 to 0.90 in most of the service station in the state of São Paulo. The major conclusion is that due strong competition the producer price which is also defined by the market is being quoted by the sugar and ethanol sector at unrealistic high value. Also, probably, real sales profit from the distributor and service stations are smaller than what is shown in Figure 45. Furthermore, there is a small leakage of the product that is sold without collecting all the taxes, but this is a very small share. The major conclusion is that real prices received by producers are lower than R$ 0.41 (US$ 0.205/liter) and the trend is for lower price in 2002 due surplus production. More than that, it is important to recognize that ethanol prices in the year 2000 and 2001 were good enough to pay for good care with the crop as demonstrated by the very good yield expected for the year 2002.

Also it become evident that prices as low as the one occurred by 1999 are below economic feasibility and triggered absence of investment by the producers. Figure 46 shows price of gasoline hydrated ethanol in service station by August 1999 and Figure 47 and 48 prices for February 2002. It is very clear that is 1999 hydrated ethanol had too low price (40% of gasoline price) while by 2002 it is 64% and 53% of the gasoline price, depending on the service station. Furthermore, it is important to remember that pure gasoline is unavailable at service stations in Brazil. This means that pure gasoline is quoted at even higher price than shown in Figure 46, 47 and 48. The cost of anhydrous ethanol is not shown in these figures, and this is the ethanol used for gasoline blending. Anhydrous ethanol cost, in average, 10% more than hydrated ethanol, which prices are shown in that figures. Assuming anhydrous
price as R$ 1.10 (for February 2002) when it reaches the final consumer (to be compatible with Figure 47) and R$ 0.88 to be compatible with Figure 48, we conclude that final price of pure regular gasoline for the consumer would be R$1.705 and R$1.696, respectively. Thus, the final conclusion is that hydrated ethanol cost for the final consumer 58.7 and 47.2% of the regular gasoline price, respectively. Average price can be assumed at the middle of these examples, that is 53%. If we apply 25% correction for the lower hydrated ethanol efficiency compared with gasoline, the final result is that ethanol has a final price to the consumer equivalent to 2/3 of the gasoline price. This is a result already shown in Figure 44, at least for some months of 2001, but what is more remarkable is that since the begin of 2000 there were only modest supplies of ethanol, which kept prices at reasonable high levels able to satisfy producers. By the coming months of 2002, price of ethanol should decline, as already shown in Figure 44 due oversupply. If oil prices keep the value of US$ 21 to 23/barrel we can expect that ethanol price (corrected by the lower energy contend will be around 60% of gasoline price in Brazil).

Such results are very satisfactory to demonstrate the economic feasibility of ethanol in Brazil. This has been achieved through a large effort of “learning by doing”. Figure 49 shows the decline in the final price of hydrated ethanol. The Alcohol Program started with ethanol prices around US$ 0.75/liter and by 1998 achieved US$ 0.20. The decline was even higher in 1999, but as already discussed this was a very low value caused by oversupply and it produced significant losses to the producers. After a small recovery by 2000 and 2001 prices are just below US$ 0.20/liter at the begin of 2002 and should decline to 0.16/liter still by 2002. Such level, probably is the lowest that can be accepted by the producer while providing them some gain. Figure 50 shows the annual production, as well as the accumulated amount of ethanol in the period 1976/1999. Considering the production of 2000 and 2001, accumulated production of ethanol has surpassed 200 million m³. This drove the “learning-by-doing” process and should be seriously considered by other countries willing to developed their sugarcane based alcohol industry. Advanced “know-how” is available in Brazil and it is worthwhile to consider this on behalf of faster agro industry development. Other important point is shown in Figure 49 where it is noticed the negligible amount of money invested in R&D in renewable sources of energy as compared with other R&D activities. This means that, probably, there is space for more cost reduction if a significant R&D effort is carried out. Combination of “learning-by-doing” and large R&D effort may prove to be extremely helpful for the establishment of a global ethanol producing activity. Further technology development can occur in the process of water/ethanol separation and in the convertion of cellulosic biomass to ethanol, as will be further discussed in section 6. Membrane separation as a total or partial replacement for ethanol distillation may have a considerable impact in ethanol derived from sugarcane production cost. Average low-pressure steam consumption is around 500kg/tonne of sugarcane processed. With no distillation it is possible to bring this value to less than 100 kg of steam per tonne of sugarcane. As already shown in Figure 33, it is possible to generate 600kWh/tC using 200kg of steam in the process. Reducing to less then 100 will push this value to more than 700kWh/tC. It is worthwhile to note that all results for the scenario developed in Figure 30 assumed 500kWh/tC of electricity generation.

Cellulosic hydrolysis and its consequent transformation to ethanol is a long-time expected technology. For sugarcane it will bring a relevant solution for the very large amount of
residues. As pointed out in the scenario for 13Mha of plantation, the assumption of electricity generation at 500kW/tC yields an amount of electricity above the Brazilians necessity for several decades. Such electricity surplus is difficulty to address, since the exportation market must be limited to neighboring countries. The best solution would be to use part of the sugarcane residues for electricity generation and what exceeds market demand should be addressed to the production of further ethanol through cellulosic material hydrolysis.

Ethanol produced may be exported to remote countries, provided a market is created. Another import economic question to analyze is that sugarcane bagasse is the potentially most economic feasibility raw material to obtain ethanol via hydrolysis. Bagasse is already available in the mills and the infrastructure to generate electricity and steam for the process is already implemented, as well as the requirements for processing the sugar juice to pure or hydrated ethanol. Essentially, this means that if hydrolysis will become a feasible technology is has to be through the use of sugarcane bagasse.

For the skeptical reader that is not yet convinced about the economic feasibility of ethanol as a fuel, Figure 51 shows the historical evolution of raw sugar price from 1960 – 1995. Prices shown significant instability with at least 4 major spikes due supply shortage and surplus. Considering the upper which presents and surplus of supply. Considering the upper curve, which presents annual prices normalized to the 1995US$ it is possible to adjust a linear plot showing price trend over these 35 years. As shown by the straight line, prices are declining at a rate of 15% per year, this is a expected trend since commodities prices are always showing a decline in time. Figure 52 shows the same results, but for world gasoline prices. The long-term trend shows a price increase. Considering that sugarcane crop can essentially be converted to sugar or ethanol, the straightforward conclusion is that ethanol prices should decline in the future. Consequently, if today we may have doubt about its economic feasibility as an alternative fuel it is enough to wait some more time and commodity prices decline will make ethanol cheaper than gasoline. This is an important consideration for countries willing to start their ethanol industry. As already pointed out before, ethanol prices at the early stage of the production may be higher compared with gasoline. But with technology transfer, R&D and with the price trends above discussed the future ethanol prices have a good chance of competing with gasoline, as is already happening in Brazil.

Figure 53 shows for the fuel ethanol industry in Brazil the annual amount of C abated. Processing of ethanol from sugarcane requires fossil fuel use in the agricultural and industrial phase. In the agricultural phase mainly as fertilizers, pesticides, indirect energy contend of equipments and direct fossil fuel derivatives used in tractors, and trucks for delivering sugarcane to the mill. In the industrial phase all direct energy required for processing is obtained from the use of bagasse. But fossil fuels are used indirectly through equipments needs in the processing process. Accounting all these fossil uses, as well as for N\textsubscript{2}O and CH\textsubscript{4} emissions which are associated with the traditional pre-fire harvesting of sugarcane, total emission is accounted as 1.28 + 0.06 + 0.24MtC/year, respectively. From the other side ethanol production as a fuel displaces gasoline avoiding the emission of 9.13MtC/year. With present practices some bagasse remains as surplus at the sugar mills and are sold for other agro-industries. Its use there abates C from the displacement of oil.
As much as 5.20MtC/year is abated. Doing the evaluation of the net C abatement we arrive at 12.74MtC/year (see Figure 53). This is a remarkable result, mainly when we examine the ratio of abated and emitted C from the use of fossil fuels to grow sugarcane and transform it to ethanol. From Figure 53 we conclude that the ratio is $14.33/1.58 = 9.1$. This figure should be interpreted in the following way: with the use of one unit of fossil fuel it is possible to produce 9.1 units of renewable energy.

Figure 54 displays the total potential C abatement expected if a sugarcane planted area of 13Mha will be developed for ethanol and electricity generation. For electricity generation it is assume that either using sugarcane residues (through gasification) or either using fossil fuels (essentially NG in gas turbines) an efficiency of conversion of 50% is obtained. It is quite interesting to note that C abatement in electricity generation is higher than in ethanol use. This occurs since in the 13Mha scenario it is assumed that electricity generation, which is, presently, carried out in few mills with inefficient technology will be fully generated through biomass gasification using gas turbines at a rate of 500kWh/tonne of cane.

6. TECHNOLOGICAL GAPS

The major one is associated with the unavailability of commercially feasible technology for conversion of cellulosic materials to ethanol. Figure 55 shows the major components of corn, agricultural residues, hardwood and herbaceous crops. It is very clear that with the availability of conversion of cellulosic and hemicellulosic materials to ethanol, agricultural residues, hardwood and herbaceous crops could be a significant source of ethanol. Figure 56 shows the complexity to convert cellulosic biomass to ethanol. Observe that all processes shown are technologically feasible. The major issue is that there are so many unitary processes that it is very difficult to obtain the final product at a cost equal or lower than ethanol from sugarcane. And if some raw biomass will be able to achieve commercial economic transformation to ethanol, sugarcane bagasse is the most promising, as already discussed in section 5.

7. CONCLUSIONS

Figure 57 resumes the major advantage of producing a fuel from sugarcane. Most developing tropical countries can produce ethanol and it could be exported to all fossil fuel importing countries. For the replacement of 50% of the gasoline in use by the year 2000 in OECD countries a sugarcane plantation over 90Mha would be needed. But if we assume further improvements in sugarcane yield and in its processing to ethanol, as well as the development of cellulosic hydrolysis, an area of 17Mha would be enough. Please note that under such circumstance, electricity cogeneration will be much lower than anticipated in the 13Mha scenario (see Figure 31 and 35).

Figure 58 presents economic results for Latin America and the Caribbean by 1998. Current account deficit was 4% of GNP; while additional hard current reserves plus compensatory capital required was US$ 21 billion. Exports declined and no significant change occurred
from the previous year regarding net direct foreign investments. Other economic indicators show the difficult economic situation of the region. As shown in Figure 57 this situation could be significantly improved if the policies of OECD countries included a displacement of 50% of the gasoline used by importation of ethanol from tropical developing countries. As much as US$113 billion could be transferred to developing countries, and if a fraction of these would be directed to Latin America and the Caribbean it should help to mitigate part of the bad economic indicators (see Figure 58).

Figure 59 is a model constructed for Brazil, assuming that in the period 1979-1992, the country would be able to export ethanol. The amount would start as ¼ of Brazilian production in 1992 (3 million m$^3$ per year) and ended with a volume of 13 million m$^3$ by 1992. With this extra revenue, and assuming total country importation would be kept at the level it was without ethanol exportation, it is possible to identify a significant decline of the country external debt. Without the potential ethanol exportation, the external debt achieved the value of US$110 billion by 1992. With the addition of the potential ethanol exportation the external debt would be US$10 billion by 1992.

Figure 60 shows the same exercise as Figure 59, but assuming that a much larger amount of ethanol will be exported by Brazil, starting at the year 2003 up to 2020. The amount of exportation is equal the total volume of ethanol produced by our 13.1Mha of sugarcane plantation (see Figure 31). The conclusion is shown in Figure 60. Even with the large revenue from ethanol, the external debt would continue to increase from the US$260 billion in 2001 to US$600 billion. This is just US$120 billion less than without ethanol exportation. This means that even with such significant effort for production of renewable energy, the future of the country economy is not good. Another curve is shown, where a curbing of external debt is obtained but this requires the revenue of ethanol exportation plus lower interest rates on the debt.

Final conclusion is that Brazil alone can make a significant contribution for the mitigation of global GHG emissions, if developed countries would like to change their policies regarding oil importation, but can not resolve its economic situation just by being the major ethanol exporter.