The role of biomass in meeting the Paris agreement

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Abstract. Recent energy scenarios, dealing with Climate Change mitigation with the purpose to limit warming up to 2°C or less by 2100, report high biomass energy participation in the primary global energy portfolio. By 2017, global biomass contributed with 5.2 EJ and average annual growth rate, in the last four yrs was 2.23%. However, the recent bioenergy growth rate must increase to meet CO2 concentration pathways aligned with the mitigation scenarios. This paper describes a bioenergy deployment strategy, based on liquid fuel and electricity joint production from sugar cane used for light duty vehicles. The pathway relies on 1st generation ethanol production, and steam power cogeneration from sugar cane waste supplemented by planted forest. Both technologies are commercial, and when used in conjunction with Biomass Energy Capture and Storage (BECCS) from sugar fermentation CO2 reach negative CO2 emissions. This yields a significant volume of GHGs abatement to contribute for the Paris Agreement. Exploring an area of 80 million hectares, from which 60 Mha is dedicated for sugar cane and 20 Mha for fast growing trees, it is possible to move a fleet of 1 billion plug-in hybrid light duty vehicles through the combination of ethanol and bioelectricity. The cost of ethanol and bioelectricity to consumers is lower than the cost of gasoline used in conventional cars and the net balance of GHGs emissions is lower than for electric vehicles.

1. Introduction

Most of the scenarios that can fulfill GHGs atmospheric concentration pathways compatible with the Paris Agreement strongly rely in the use of biomass as a source of energy.

Figure 1 extracted from the IPCC Global Warming of 1.5°C report shows that the biomass share on the 2050 energy supply portfolio is larger than solar and wind in four (S1, S2, S5, IEA/WEM) of the five possible scenarios that satisfy the target of 1.5°C temperature increase. Already by 2014, the 5th Assessment Report [1] quotes bioenergy as a significant contributor for friendly climate change scenarios. The document presents an economic evaluation of the cost to society to guarantee modest global temperature increase up to the year 2100. The economic figures displayed are relatively modest, even for CO2e concentrations around 450 ppm. Figure 2 shows that average annual costs are below 0.1% of global national product. However, even more interesting is the result presented in Figure 3 in which an analysis is introduced to identify additional costs if some important technologies for GHGs emissions face a limited deployment. As can be noted, if the use of further bioenergy is limited, the median value, extracted from several scenarios’ evaluation, points to an increase of 50% in the cost. In the case of not using Carbon Capture and Storage (CCS), the overcost exceeds 120%. Just as a useful yardstick, note that abandonment of nuclear energy use implies in very modest overcost (around 5%). Such results highlight the importance of biomass not only by its contribution for reducing the cost to climate change mitigation but, also, due the fact that CCS is being considered as an important...
technology for achieving negative CO$_2$ emissions when applied in conjunction with bioenergy [(1); (2)].

Considering its relevance to contribute to climate change mitigation, we decided to perform a detailed analysis of the potential of the use of biomass for energy generation, mainly in the transportation sector.

![Figure 1](image1.png)

**Figure 1.** Primary energy supply for the four illustrative pathway archetypes plus the IEA’s Faster 4 Transition Scenario [3]. The category ‘Other renewables’ includes 6 primary energy sources not covered by the other categories, for example, hydro and geothermal energy.

![Figure 2](image2.png)

**Figure 2.** Global cost for climate change mitigation at different levels of global temperature increase
using CO\textsubscript{2} concentration in atmosphere as a proxy. IPCC has examined many scenarios from different authors and shows the median, maximum and minimum costs for different CO\textsubscript{2} atmospheric concentration. The Y-axis shows total accumulated costs in the period 2010-2030, 2010-2050, and 2010-2100. Figures at the bottom in the white panel are average annual reduction in Global Product in order to make the necessary investments to achieve desired level of mitigation. The range of values is represented minimum and maximum costs for countries. Usually the cost is larger for developing countries.

Figure 3. Evaluation of potential increase in the cost to perform climate change mitigation in case some technologies are not accepted by society.

2. **Biomass as a source of energy**
Table 1 shows the participation of biomass energy at global level, by 2017. Biomass, share is 12.4%, and most of it is due to traditional biomass uses (7.8%). Another important point is the short-term growth rate, also displayed in 1. Biomass use growth rate occurs at a very modest rate (2.3%/yr) during the period 2014-2017. Thus, present biomass supply contribution, and present growth rate is insufficient to reach the values shown in Figure 1 for scenarios that are able to satisfy the Paris Agreement, and do not require significant energy use reduction (as is the case for S2, S5 and IEA/WEM). Taking as example S2 scenario, which shows modest increase in total energy supply for the future, biomass represents 20.2% of total supply, translating in the absolute amount of 115 EJ, already by 2030, and 160 EJ by 2050. To understand how to increase biomass supply from the 2017 value of 52.3 EJ to 115 EJ by 2030 and 160 EJ by 2050, it is necessary to examine its present final energy uses and determine which are the opportunities that justify potential higher growth rates in the near future as forecasted in figure 8.12 in [4].
Table 1. Biomass production and growth rate by final use sector 2017.

| Final use sectors | Bioenergy type | Energy share consumption (%) | Specific final uses share | Value (EJ/yr) | Share of the sector (%) | Share of all energy (%) | Growth rate 2017-2014 (%/yr) | Energy supply (EJ/yr) |
|-------------------|----------------|-------------------------------|---------------------------|--------------|------------------------|-------------------------|----------------------------|----------------------|
| Transport         | biofuels       | 32                            |                           | 3.50         | 3.00                   | 0.96                    | 3.44                       | 3.50                 |
|                   | ethanol        |                               |                           | 2.24         | 3.70                   |                         |                           |                      |
|                   | biodiesel      |                               |                           | 1.02         | 1.25                   |                         |                           |                      |
|                   | HVO            |                               |                           | 0.18         | 12.60                  |                         |                           |                      |
| Electricity       | Bioelectricity | 20                            |                           | 1.55         | 2.11                   | 0.42                    | 9.39                       | 6.46                 |
| Heat              | Bioheat        | 48                            |                           | 41.95        | 23.75                  | 11.40                   | 1.86                       | 42.35                |
|                   | Residencial (tradicional biomass) | | | 28.70 | 16.25 | 7.80 | 0.20 | 28.70 |
|                   | Residencial (modernl biomass) | | | 5.15 | 2.92 | 1.40 | 5.40 | 5.35 |
|                   | Industry (modern biomass) | | | 8.10 | 4.58 | 2.20 | 5.50 | 8.30 |
| All               |                | 100                           |                           | 47.00        | 12.78                  | 2.23                    | 52.31                      |

1 According with accounting criteria used by [5]
2 Calculated from [5] data using criteria shown in [6]
Source: Authors using data from [5] and [6]

Traditional solid biomass, the largest demand for biomass, is mainly used by low-income population and all UN programs dealing with human life quality improvement aim to reduce this activity. Heat supply for residential and industrial uses represent the 2nd major biomass demand and is expected to grow through increased sales of wood pellets for domestic heating in Europe (see Table 1 residential sector (modern biomass)), while industrial heat use also shows a similar growth rate (5.50%/yr). The third major sector for biomass use is the transport sector, in which ethanol and biodiesel, including hydrotreated vegetable oil (HVO), with respectively 106 billion and 31 billion liters per year displace gasoline and diesel. Average annual growth rate is 3.44%. Finally, bioelectricity is the 4th largest biomass use, with a large growth rate (9.39%/yr). Total biomass use growth rate value is small (2.23%/yr), and insufficient to approach the expected figures for 2030 and 2050 in the IPCC scenarios presented in Figure 1.

Based on the global bioenergy perspective this paper concentrates in ways to increase the growth rate for bioenergy in the transport sector, in particularly, ethanol and bioelectricity from sugar cane. Sugar cane was selected because it provides both liquid fuels and electricity, and its conversion presents a favorable energy balance and modest lifecycle GHG emissions [7].

According with IEA [8], global tested performance of light duty vehicles (LDV) was 7.7 L of gasoline equivalent per 100 km. Thus, considering average annual displacement of 15,000 km and that real performance is 80% of tested results [9], global gasoline equivalent consumption in 2017 was 1,375 billion liters for 1 billion LDV fleet, which is the number of LDVs in use by 2017 according to ETP. This figure represents 23.7% of the global oil consumption. In this sector, there are good expectations for significant gasoline equivalent reduction, through energy efficiency improvements, and the use of hybrid electric cars. As an example, the conventional Toyota Prius model tested fuel performance is 70% better than traditional internal combustion engine (ICE) cars of the same size [10]. This means that from the technical point of view total gasoline equivalent consumption for the 1 billion cars fleet could be reduced from 1,375 to 809 BL/yr. A hybrid vehicle can easily be adapted to use neat ethanol, as has been demonstrated by its flex fuel version, already commercialized in the Brazilian market. Assuming that this occurs, some 1,156 BL of ethanol would be required. Such
production level would increase ethanol fuel share from 0.90% in the 2017 liquid fuel market [5] to 13.0%, while total primary energy from biomass feedstock would increase from 5.6 EJ to 80.9 EJ. This high increase opens an opportunity to bring biomass supply to the expected value shown for the S2 scenario (see Figure 1).

Electricity generation based on biomass feedstock, also known as bioelectricity, has a very modest participation in the overall biomass portfolio – 0.42% (see Table 1). Perspectives for higher bioelectricity generation are mainly tied to co-firing. Co-firing of biomass and coal is used by utilities in developed countries as a way to mitigate GHGs emissions. Usually 10% of coal is replaced by biomass since at these level minor modifications in the coal-based power plant is needed [11]; [12]. Since coal thermal plants, presently, generate 40% of all electricity [13], this means that 10,000 TWh/yr at an average efficiency of 33% consumes 100 EJ of coal. If 10% of this energy is replaced by biomass, biomass share will increase 10 EJ/yr. Thus, this is another activity with huge potential to increase biomass supply and fulfill the proposed energy profile set by scenario S2.

Considering that ethanol used for LDVs and bioelectricity are the biomass uses with the best perspectives for significant growth as required to fulfill the Paris Agreement, this paper focus on the feasibility to increase ethanol (see Box 1) and bioelectricity demand, improving substantially the biomass share in the global energy supply, and is GHGs emissions friendly.

**Box 1 Ethanol use in Brazil**

Brazil has been one of the major players in the use of sugar cane biomass to produce ethanol for light duty vehicles (LDV). Already, around the 2nd decade of the last century, ethanol was blended to gasoline in some regions of the country, in variable amounts but usually below 10%, due economic reasons. The country imported all gasoline consumed creating an economic burden while excess sugar supply posed a problem for agriculture, an important sector of the country’s economy. Only by 1975 an official fuel blending program using ethanol was established, and again motivated by economic reason. By 1973 and, also a few years later, oil prices soared, and its importation represented around 50% of the importation expenses [14].

The program, known as Alcohol Program, was initially designed to increase sugar cane planted area in order to produce ethanol in an amount large enough to guarantee a 20% blend with gasoline. Economic incentive was provided by the government through low interest money for the necessary investment while a tax was added to gasoline to increase its price and guarantee money needed for the expansion of the activity. The success was so large that by 1979 the first LDV running exclusively with ethanol was commercialized. By 1984, more than 90% of new cars produced in the country were neat ethanol powered. Unfortunately, due improper planning, and the low cost of oil in late 1980s, ethanol supply was not able to match demand creating a serious fuel shortage issue that reduced public confidence in neat ethanol cars [14].

Neat ethanol cars production declined and by the end of 1990s, it approached to zero, but ethanol continued to be consumed as a fuel through the 20 to 25% blend in gasoline. This minimum consumption was guarantee since no pure gasoline was sold in any region of Brazil. Ethanol powered cars retook its prestige when flex fuel cars were offered to consumers. Such cars are available to run on ethanol, gasoline or any blend of these two fuels. This means that the car driver can select the fuel he wants to use, based in price, and since by law neat ethanol must be offered in all gas stations. Such freedom to choose the fuel, once again increased the ethanol supply market, and a voluntary together with the compulsory blend market is being maintained for decades (see Figures 4 and 5).
Complementing Box 1, another aspect of the use of ethanol as a liquid fuel displacing gasoline is the possibility of sugar mills commercialize electricity generated through the burning of sugar cane bagasse for the operation of steam turbines [16]. The ethanol industry, as any chemical industry
requires heat for processing sugar cane in ethanol. Traditionally, sugar mills use bagasse as a source for heat, and for electricity internal demand. As an example, by 1986, mills in Brazil started to overproduce electricity and sell it to other users, usually through the existent grid network. In a detailed study [17] more than 100 of the 350 mills in operation were selling surplus electricity to consumers. According with the Brazilian Energy Balance [18], around 21 TWh were exported by all sugar mills, which correspond to 6% of the total country electricity consumption.

Surplus electricity generation in sugar mills is quite common in many countries [19]; [20]), and the potential is significant. Biomass boilers usually are designed for low pressure steam generation since most of the process energy demand is low quality heat. As electricity prices increase investors become interested in installing high pressure boilers in sugar mills and improve the cogeneration process. Very high-pressure boilers (2.350 psi) are common in pulp and paper industry [21] while high-pressure boilers (1.470 psi) are becoming popular in the sugar/ethanol industry in Brazil [22]. The main reason for the difference between the technologies in the two sectors is the capacity factor. The pulp and paper industry operates year-round and sugar mills operation is restricted to the harvesting season, which usually in Brazil lasts 200 days. Consequently, investment in electricity generation has to be lower in sugar mills in order to provide the same rate of return obtained in the pulp and paper sector. Limited to 1,470 psi and 520°C, typical generation figure can reach 100 kWh/tcane processed, depending on the amount of heat demanded in the process. Very efficient sugar mills use around 350 kg of steam/tcane and can generate over 100 kWh/tcane, from which 30 kWh are internally consumed [23].

Traditional operation uses bagasse as feedstock for boilers but with mechanical harvesting, and strong environmental regulation, green cane harvest is becoming more frequent. In this circumstance, sugar cane tops and leaves are also available during harvest and some mills are using a share of them to feed boilers [24]. As pointed out [16] using 40% of this extra biomass it is possible to generate 170 kWh/tcane, from which 135 kWh is exported.

3. Environmental issues

Improving technology is part of the requirements to increase the use of bioenergy. Limiting environmental impacts is another important consideration. Environmental impacts occur in atmosphere, land, and water.

In principle bioenergy combustion is CO₂ free, since its emissions to the atmosphere are offset by the growth of the next crop generation, provided we are considering continuous harvest and plantation process. In reality, there are emissions to atmosphere in the form of CO₂ due the use of fossil fuels in the cropping and transportation stages. Furthermore, non- CO₂ GHGs are emitted in the process due soil disturbance and fertilizers use. It is necessary to consider also that new plantation activity can displace other agricultural products, and these must be replaced either by new plantations in other areas in the same region or even in other countries or replaced by similar agricultural product that must be produced in new land areas. This last issue is known as indirect land use change.

Regarding ethanol derived from sugar cane produced in Brazil, one of the most complete lifecycle studies was carried out in 2010 by US-EPA with the participation of Brazilians experts [16]. According with such study, full lifecycle GHGs emissions for ethanol is 36 g CO₂e/MJ when produced in a sugar mill that generates 75 kWh/tcane and 8 g CO₂e/MJ when sugar mill generates 170 kWh/tcane. Thus, it is possible to note the bioelectricity relevance to climate change, mainly remembering that average gasoline used in the United States emits 93 g CO₂e/MJ [16]. The conclusion is that using ethanol to displace gasoline can reduce GHGs emissions by 85 gCO₂e in the most favorable situation. This situation also considers the substitution of bioelectricity for fossil based electricity. These figures are important since the values for the world can be even more impressive if similar agricultural practice in Brazil can be replicated in other tropical countries. The last figure can increase since 1 liter of ethanol displaces 0.7 liter of gasoline instead of 0.66 liter, as calculated based on the energy contend of both fuels, due the ethanol higher octane number than gasoline. This allows higher ICE compression rate improving energy consumption. Another reason for the increment in the
figure is the fact that oil refineries in most countries are less efficient than in the USA, and, finally, it considered that EPA evaluation for Brazilian ethanol was calculated for product transported to the US. That is, emission due to ship transportation is included. Noting these factors, we can expect average global GHGs emissions of gasoline greater than 100 g CO\textsubscript{2e}/MJ, while ethanol emissions can be below 8 g CO\textsubscript{2e}. Thus, a figure of 92 g CO\textsubscript{2e}/MJ is a good estimate for emission reductions in the most favorable operation case for sugar mills that is 135 kWh/tcane exportation. Regarding uncertainty, EPA study states that the calculated value of 8 g CO\textsubscript{2e}/MJ has an uncertainty of plus or minus 8.4 g CO\textsubscript{2e}/MJ, under a confidence level of 95%, implying that the emission reduction, compared with gasoline is a value between -0.4 and 16.4 g CO\textsubscript{2e}/MJ. Consequently, ethanol LCA, obtained from this information ranges from 40.5 to 57.3 g CO\textsubscript{2e}/MJ.

According with a recent compilation of several LCA studies covering 1\textsuperscript{st} generation feedstock [7] shown in Figure 6 it is possible to observe that medium value for 10 studies dealing with sugarcane is 52.4 g CO\textsubscript{2e}/MJ, while the range of 75% to 25% of all values spreads from 60 to 40 g CO\textsubscript{2e}/MJ. Thus, the value and uncertainty quoted in EPA, 2010 almost overlaps with most of all new results.

![Figure 6. Carbon footprint of 1\textsuperscript{st} generation biofuels.](image)

Considering a fleet of 1 billion LDV, an average annual displacement of 15,000 km, and the average real efficiency of 80% of the 7.7 L/100 km [8], replacement of gasoline by neat ethanol can reduce annual GHGs emissions by 4.25 GtCO\textsubscript{2e}. This is a remarkable result since global road transport CO\textsubscript{2} emissions by 2016 was around 6 GtCO\textsubscript{2} and growing at a business as usual rate of 2%/yr will reach 9 GtCO\textsubscript{2} in 20 yrs [13], a period long enough to replace all the present gasoline ICE car fleet.

One serious issue is the large extension of land necessary for the agricultural activity. Considering a reasonable productivity of 7,740 L/ha (90 t cane/ha and 86 L/tcane), each LDV requires 0.27 ha of harvested sugar cane, and the 1 billion fleet needs 270 million ha. This is based in the tested performance of 7.7 L of gasoline/100 km, an increase of 80% for real driving situation, as already mentioned above, and that 1 L ethanol displaces 0.7 L gasoline [15]. Average LDV annual displacement is 15,000 km. To provide a yardstick, the current global sugar cane harvested area is around 27 Mha [25]. Enlarging this area by a factor of 10 sounds a challenge. Nevertheless, present technology advances can contribute for the ethanol use scenario. Hybrid vehicles are a real and quite promising alternative to ICE cars. Plug-in hybrid cars have fuel efficiency around 40 km/L of gasoline if 55% of the annual displacement occurs in the city, where electricity from the grid is used [10]. For 1 billion plug-in hybrid cars, total sugar cane harvesting area is cut down from 270 Mha to just 60 Mha. Such global land area is feasible because it corresponds to an area just twice as large as the present area. Furthermore, electricity required for the plug-in hybrid cars is produced from sugar cane wastes. At a level of 135 kWh/tcane exported by the mill, the 60 Mha can supply 728 TWh, which is enough
to feed 52.9% of the fleet. Kindly be informed that electricity is used mainly in city traffic that represents 55% of annual car displacement. Electric efficiency is 6 km/kWh. [10].

The inconvenience of such solution is that global GHGs emissions reduction will decline from the 4.25 GtCO$_2$e/yr to only 1.06 GtCO$_2$e/yr, even if we can provide supplementary CO$_2$-free electricity to feed the remaining 47.1% of the plug-in hybrid fleet. However, this decline is relative to the plug-in hybrid LDV powered by gasoline. In reality, for achieving Paris Agreement target the account must be performed with respect to present situation where fossil based liquid fuels are used in ICE cars. Compared with the present situation, GHGs emissions reduction is still quite high, reaching an annual value of 4.0 GtCO$_2$e, out of which 2.90 GtCO$_2$e is caused by gasoline consumption decline due to the replacement of ICE by plug-in hybrid LDV, thus independently of ethanol supply, but depending of zero emission electricity.

With respect to local atmospheric pollution, ethanol fuel also presents a good performance. In a real measurement exercise, that used the metropolitan area of São Paulo, with a population of 20 million people and more than 5 million cars from which 2 million are flex fuel, has served as laboratory. Figure 7 shows variation in particulate matter concentration and other local pollutants in the city’s atmosphere during a period in which ethanol fuel use in cars had shown a significant decrease due to changes in the price difference with respect to gasoline [26].

![Figure 7](image_url)

Source: Salvo et al, 2017

**Figure 7.** (a) Estimated changes in pollutant concentrations. For varying composition, size range, and time-of-day window, in the São Paulo metropolitan area as the gasoline share in the flex-fuel fleet rises from 30 to 80 percentage points. Submicron particles and Black Carbon correspond to readings at 08:00, PM2.5 are 24-h means, and ozone are afternoon means between 12:00 and 16:00. Sample periods are January to May 2011 for submicron particles, October 2010 to April 2011 and October to November 2012 for BC, and November 2008 to May 2013 for PM2.5 and ozone and (b) Fuel share variation among flex-fuel vehicles January to May 2011.

Land use change will occur during the expansion of sugar cane crop as has happened, for example, in Brazil as shown in Figure 4 (see Box 1). By 2017, the harvest sugar cane area, for food and energy, has been evaluated as 10.2 Mha, from which the Southeast and Center west region is responsible for more than 90% of the area. Most of these areas were occupied by other crops or used as pastures since native vegetation has been removed at the beginning of the 20th century. Accurate quantification of historic vegetation replaced by sugar cane is not available. Nevertheless, it is useful to rely on studies available dealing with indicators such as carbon debt [27] and ecosystem carbon payback time [28] that focus on upfront land use change (LUC) emissions arising from the conversion of land to bioenergy production. IPCC [6] concluded that, on average, payback time for land use impact recovery can take from a few years up to centuries, as shown in figure 2.12, Chapter 2: Bioenergy [6]. Analyzing that it is easy to see that previous use of land has a significant impact in the payback time,
as well as the type of vegetation used for bioenergy feedstock. For sugar cane planted in grassland a period of 5 to 6 years is required to compensate emissions due to direct land use changes. The replacement of other crops implies in payback times usually lower than for grassland. Open ranch pasture lands usually are soils with poor productivity, thus payback time can be very similar to degraded soils that is less than 1 yr [6].

Such information is useful when planning for sugar cane crop expansion as discussed earlier in this section, and in more detail in another paper [29]. Considering that the objective is doubling global sugar cane planted area in 20 years, and taking, for example, a carbon payback time of 4 years for the average areas used, the annual expansion, assuming linear growth is 6.6%. Since it takes 4 years to fully compensate emissions induced by direct land use changes, in the fourth year total environmental damage reaches a value around 26.4%. This means that up to the 8th yrs, it is necessary to consider some amount of GHGs emissions on the CO₂ footprint of bioenergy replacing fossil energy, from the abatement value calculated without accounting for direct land use changes. Moreover, in the study used as reference for this paper, [16], LUC and ILUC has been considered when calculating ethanol emissions from sugar cane produced in Brazil. This issue is determinant for the choice of biomass feedstock and for the proper selection of the land where biomass will grow. Land use change is accounted in this study, since all our calculated figures rely on the evaluation of sugar cane emissions that may occur if Brazil expands its production following historical trends, as it was built-in the EPA [16] study. Thus, it is clear that for sugar cane area expansion at the modest rates (6 or 7%/yr) proposed in this study, it is necessary that sugar cane is planted in areas with low vegetation intensity.

Water availability is essential for biomass growth and at least 1,000 mm of natural precipitation is needed for some vegetation, even for the most water resilient species. Sugar cane crops requires more water than average crops, but is resistant to seasonal draught, while demanding large amount during the initial growth period. Thus, not all regions of the tropical world are suitable unless artificial irrigation is used. In the Southeast area of Brazil, sugar cane is grown with modest irrigation, but in the Center West region, irrigation is required with more frequency. Such practice has impact in the ethanol energy balance, and consequently for emissions during the agricultural phase. The impact can be significant, even for low levels of irrigation. Assuming the necessity of 200 mm of irrigated water per year, each ha uses 2,000 m³ of water. Water is usually supplied at a pressure of 50 m of water column [30], implying that such water is lifted, at least, 50 m high. Total mechanical energy needed is 1 GJ/ha equivalent to 1/3 of a MWh/ha. Considering losses, such value can reach 0.5 MWh/ha. Groundwater is also commonly used and, in this condition, water has to be raised up to 200 m. Thus, electricity demand can grow to 2.0 MWh/ha. Fortunately, as already discussed, each tonne of sugar cane easily generates 100 or more kWh, but such energy provision can almost double internal process electricity demand in the most stringent condition.

Water for irrigation is one of the issues regarding environmental impact. Another aspect quoted in the literature is rainfall water capture by the crop. Usually 1/3 of the rainfall water is used by the vegetation, which means that for an average annual precipitation of 1,500 mm, 5,000 m³/ha is removed from run-off water. This is a real issue but, from one side it is minimized because in the absence of sugar cane crop another type of vegetation would be there absorbing a fraction of the 5,000 m³/ha. From the other side, decrease in run-off water is a problem in water poor regions, which are not suitable for commercial agricultural activities, and cannot be used for ethanol production.

4. Future possibilities – technical aspects
As already commented, electricity generation in modern sugar mills uses limited technical solutions due economic restrictions imposed by part-time annual operation. The figures presented in the EPA report [16] that is 170 kWh/tcane, using all bagasse plus 40% of the remaining waste generated during green cane harvest implies in thermal conversion efficiency lower than 20%. Electricity generation with average efficiency of 26.5% have been proposed in projects [31] but provides low rate of return. In order to circumvent this issue, it is proposed to operate mill’s biomass power plant for a longer period of the year, relying in other biomass feedstock. As an example, in Brazil, eucalyptus plantation
for energy uses is quite common and its costs are low. According with BIG [32], there are 56 thermal plants using biomass from forest with total capacity of 427 MW. In addition, in the last few years, maize has been used in some sugar mills with the purpose to extend their operational period. For such extra time of operation, required energy is obtained from forest biomass, particularly, eucalyptus [33]. As reported by one of these mills, not only heat and electricity is produced for their operation, but also surplus electricity sold to other consumers. As much as 1,000 kWh/t of eucalyptus is available for sale [33]. Considering that during ethanol production heat is demanded, such figure endorses the value of 1,250 kWh/t of eucalyptus used in our paper during the off-harvest period.

Taking a real case, where sugar cane harvest season occurs for 208 days, extending electricity generation by other 90 days through eucalyptus use can increase electricity sales from 135 kWh/tcane to 208 kWh/tcane. Consequently, higher investment in the power plant can be justified. Achieving 26.5% efficiency when using sugar cane wastes, and 31% when using eucalyptus means a gain of 27.8% in power generation pushing electricity sales to a new mark of 268 kWh/tcane. Such new figure has an important impact when the LDV scenario considers plug-in hybrid car fleet. Such amount of electricity, sold by ethanol producers, implies that they can offer 98.5% instead of the 52.9% share of the power demanded by the 1 billion car fleet, as calculated earlier. Thus, with better generation efficiency and eucalyptus, the plug-in hybrid fleet energy requirement is practically supplied by efficient sugar mills. Table 2 provides a summary on the several electricity generation and surplus electricity potential as a function of the technology used in sugar mills.

Table 2. Summary of electricity generation and potential sales by sugar mills for the several options discussed in the text.

| Type of Mill     | Source       | Feedstock           | Season   | Generation efficiency (%) | Operation (days/yr) | Generation (kWh/tcane) | Surplus for sale (KWh/tcane) |
|------------------|--------------|---------------------|----------|---------------------------|---------------------|------------------------|-----------------------------|
| Low efficiency   | EPA, 2010    | bagasse             | harvest  | 8.20                      | 208                 | 70                     | 40                          |
| High efficiency  | EPA, 2010    | bagasse + 40% straw | harvest  | 20.00                     | 208                 | 170                    | 135                         |
| High efficiency  | EPA, 2010    | bagasse + 40% straw | harvest  | 20.00                     | 208                 | 170                    | 170                         |
|                  |              | eucalyptus          | non-harvest | 20.00                  | 90                  | 170                    |                             |
|                  |              | bagasse + 40% straw | all year  | 20.00                     | 298                 | 244                    | 208                         |
| High efficiency  | This study   | bagasse + 50% straw | harvest  | 24.55                     | 208                 | 209                    | 169                         |
|                  |              | eucalyptus          | non-harvest | 31                      | 90                  | 229                    | 229                         |
|                  |              | bagasse + 50% straw | all year  | 26.50                     | 298                 | 308                    | 268                         |

Source: Authors

Another technical advance is expected from LDVs energy efficiency overall improvement, as well as from the sugar cane activity if the flex fuel plug-in scenario is well accepted by consumers. According our earlier discussion, our scenario proposes that the mark of 1 billion cars using ethanol and bioelectricity will be achieved 20 years from now. According with IEA [8] LDV energy efficiency will grow by 2%/yr. For ethanol production, a more modest efficiency increase of 0.5%/yr is assumed. Composing these figures, 20 yrs from now it would be possible to use 49% less energy in the car fleet while producing 10.5% more ethanol and bioelectricity from the 60 Mha of harvested sugar cane already mentioned. Thus, instead of providing energy for 1 billion cars it would be possible to power 1.65 billion cars. Regarding land area for our example, it is necessary to add the land dedicated to
eucalyptus plantation. Using again real figures valid for Brazil, 20 tonnes of wood per year can be harvested from each planted hectare [33]. Since eucalyptus is being used for electricity generation in the sugar cane off-season period there is no ethanol production and, consequently, there is no process steam demand. Thus, all steam turbines operate in condensation mode. Assuming 14 GJ/tonne and an efficiency of 31% for electricity generation, each tonne generates around 1,250 MWh. Since burning sugar cane wastes in high efficiency (26.5%) steam power plant sells 178 kWh instead of 135 kWh/tcane at 20% generation efficiency, eucalyptus demand when selling the equivalent to 208 kWh/tcane is 16.6% by weight of sugar cane. Furthermore, considering that eucalyptus is used for 90 days and sugar cane wastes during 208 days, it requires 32.3% of the sugar cane harvested area. Kindly be informed that sugar cane productivity is 90 tonnes/ha, while eucalyptus is 20 tonnes/ha. Thus, total land area used for both biomass feedstocks is 79.4 Mha. The new land area figure looks high, but it is useful to remember that 20 yrs from now, this area can provide fuel and electricity for more than 1.6 billion cars. Furthermore, eucalyptus for energy use is harvested every 5 yrs [34], and during this period, it stores C. Figure 8 shows the CO₂ sequestration profile, for a plantation that expands at a linear rate, during the time set in our scenario (20 yrs). The contribution during such period stabilizes at a small value (2.90 t CO₂/ha) but deserves to be added to the other mitigation quantities already discussed. Such low value shows that the use of another largely suggested form of CO₂ mitigation, known as C sequestration by biomass, has to be compared with our scenario. Obviously, if the proposal is the use of afforestation/reforestation to sequester C, then eucalyptus would grow for longer period until maturity, storing more C than shown in Figure 8. Nevertheless, using typical values for Brazil, maturity is achieved around 21 yrs, when some 60 t of eucalyptus/ha would sequester near 30 tC/ha (105 t CO₂/ha) that is a performance 36 times better than the one achieved in our scenario. This result is in agreement with [2]. Nevertheless, the total amount of CO₂ sequestered in the 19.4 Mha of eucalyptus plantation is 2.04 Gt CO₂, half the value obtained in our scenario, and with no financial return since the plantation has to be maintained forever.

**Figure 8.** Annual CO₂ sequestration by continuous eucalyptus plantation and harvest for a period of 20 years at linear expansion of the planted area.
Biomass Carbon Capture and Storage (BECCS) is another valuable technology that can contribute for the flex fuel plug-in hybrid car scenario under analysis (see Box 2).

**Box 2 – BECCS from biochemical ethanol production**

As discussed in the literature, Carbon Capture and Storage (CCS) is mainly associated with CO\(_2\) capture from fuel combustion. Such technology has been deeply evaluated [6] and the conclusion is that can be used but, implies in increase in primary energy requirement to produce the same amount of useful energy. This is consequence of the large amount of extra energy consumed for removing CO\(_2\) from combustion gases. Even with pre-combustion technique, which requires primary fuel gasification, primary energy increases [6]. When carrying out ethanol production through the traditional biochemical fermentation process sugar is transformed in ethanol and CO\(_2\). Thus, fermentation vessels installed in many sugar mills are closed and have an escape valve for CO\(_2\) damping in the atmosphere. Stoichiometric calculation shows that glucose and other fermentable sugars yield 960 gCO\(_2\) for each 1,000 g of ethanol. Such CO\(_2\) is quite clean and classified as proper for food industry use since the only contaminants are ethanol and water carried out by the gas exhaust flow. Note that for the ethanol, most mills cool down the flow gas to remove it due to its economic value.

As explained in Box 2, pure CO\(_2\) is a co-product of ethanol, and instead of being dumped in the air, can be transported and stored in order to perform BECCS. Energy is necessary for further water removal, transportation, and storage. Most of the energy required is in the form of electricity for CO\(_2\) compression and has been quoted at 6 kWh/t of sugar cane processed [35].

Returning to our discussion in item 3) we stated that based in [16] results, the use of ethanol as a replacement for gasoline can reduce GHGs emissions by 92 gCO\(_2\)/MJ. Adding to this figure further electricity generation due higher efficient steam turbines plus extra electricity generated by eucalyptus, and CO\(_2\) removal by BECCS it is worthwhile to recalculate total emission abatement.

The first account takes care of excess electricity generation. EPA assumed the sales of 135 kWh/tcane. With better energy efficiency plus eucalyptus, it is possible to sell 268 kWh/tcane. Assuming this electricity replaces the same amount generated by average NG power plant (31% efficiency), and discounting all emissions attributed to biomass generation, GHGs emissions are reduced by 39.2 gCO\(_2\)/MJ, based in EPA, 2010 results. This value is obtained from EPA, 2010 data, through a linear relation taking into account the amount of electricity generate in our scenario (268 kWh/tcane) and the value quoted in that study (135 kWh/tcane) The second account includes BECCS abatement that is 96% of the net amount emission of ethanol, which is 39.12 gCO\(_2\)/MJ [36]. The third account is addition of C sequestered by eucalyptus planted as energy feedstock for efficient mills with the value of 2.90 tCO\(_2\)/ha, as above calculated. Considering the amount of sugar cane and eucalyptus consumed in the mill (1000 kg and 71.8 kg, respectively), the last figure represents 5.77 g CO\(_2\)/MJ.

Kindly be informed that each t of sugar cane produces 86 L of ethanol, and each L of ethanol has 21 MJ of useful energy. Adding the three values to the 92 gCO\(_2\)/MJ avoided emission from gasoline displaced by ethanol, the final value is 176.13 gCO\(_2\)/MJ. This figure is an overestimation because we assumed GHGs emissions from eucalyptus to be equal emissions from bagasse and sugar cane wastes. These two biomass emissions are low since the only real contribution to the GHGs budget comes from non-CO\(_2\) GHGs emitted in the biomass combustion plus GHGs emitted in the transportation of the waste biomass. To make the correction, it is necessary to deduct emissions due eucalyptus plantation and management. A complete estimate for eucalyptus used for energy [37] concludes that around 12.15 g CO\(_2\)/MJ is a good figure for these contributions. Since eucalyptus share in our primary biomass feedstock weight is 7.18%, we must reduce total emission abatement from 176.10 to 174.49 gCO\(_2\)/MJ. Figure 9 synthesize GHGs emissions contributions for the different types of mills discussed.
in the text. This translates in GHGs abatement of 315.1 kgCO\textsubscript{2e}/t cane when replacing gasoline and is useful to quantify any financial premium value associated to the proposed scenario. Taking, for example, a carbon tax value of US$ 30/t CO\textsubscript{2}, each tonne of sugar cane processed in ethanol fuel and electricity receives US$ 9.45, as a premium due sustainable development. Another useful indicator is that with the harvest of 60 Mha of sugar cane and 19.4 Mha of eucalyptus used to displace conventional gasoline ICE by flex fuel plug-in hybrid cars reduces GHGs emissions by 1.70 GtCO\textsubscript{2e}. This is the value when ethanol replaces gasoline in similar type hybrid cars. However, the comparison has to be made with present situation that is use of gasoline ICE cars. Thus, we have to consider the difference in emission of ICE cars and plug-in hybrid car using gasoline. For this account consider the performance of such ICE cars as 10.39 km/L and of hybrid at 40 km/L. Considering emissions for the 1 billion ICE car fleet is 4.62 GtCO\textsubscript{2e}, and 1.20 GtCO\textsubscript{2e} for the hybrid car fleet, both using gasoline, we must add the difference between these two values to the value just quoted above when using ethanol (1.70 GtCO\textsubscript{2e}). The final value is 5.12 GtCO\textsubscript{2e} - an impressive value compared with global road transport CO\textsubscript{2} emissions of 6 GtCO\textsubscript{2} in 2016 [13].

![GHGs emissions for gasoline and ethanol used as fuel for all types of mill operation discussed in the text. Note that the white line shows final emission value for ethanol, since it is composed by positive and negative components. Error bars are due uncertainty on lifecycle analysis of ethanol, as discussed in item 3.](image)

Source: Authors based in [16] data and in figures calculated by authors.

**Figure 9.** GHGs emissions for gasoline and ethanol used as fuel for all types of mill operation discussed in the text. Note that the white line shows final emission value for ethanol, since it is composed by positive and negative components. Error bars are due uncertainty on lifecycle analysis of ethanol, as discussed in item 3.

5. Future possibilities - economic aspects
Sugar cane and fast growing trees are the feedstocks to be used to power LDVs around the world, and the plantation and industrial facilities to transform the primary energy in final energy forms are available in many countries. Economic feasibility is site specific, making accurate universal costs evaluation difficult. While in reality, the final price of sugar, which is dominated by the cost of sugar cane, as happens with ethanol, is very similar in all producing countries that trade in the international sugar market, since sugar is a commodity. The major uncertainty in different countries’ costs is due to government interference through subsidies, tax applied, and special financing conditions. To provide
some indicative figures, this paper uses economic data and private environment context from Brazil. Furthermore, since our aim is, also, to provide governance guidelines that can facilitate the technology pathway discussed, Brazil may serve as an example (see Box 3).

**Box 3- Economic aspects of high efficiency power generation in sugar mills**

Hydrous ethanol (92% pure) is sold in Brazil to final consumers, in producing regions, by 70% of the gasoline price and competes with gasohol (27% anhydrous ethanol and 73% gasoline) since all service stations must supply both fuels. Anhydrous ethanol consumption is compulsory since it is blended in all gasoline, as established by law. Figure 5 (Box 1) shows the evolution of the voluntary market, as well as of the compulsory market of ethanol.

Ethanol price is a function of sugar cane price, which corresponds to 60% of its total cost. Operational cost (20%), and investment plus profits (20%) complement the ethanol cost. The fixed cost of conventional sugar mills is US$ 70/tcane of annual processing capacity, and low efficiency cogeneration facilities, which are connected to the mills, have a cost of US$ 1200/kW [22]. Thus, total investment is US$ 90/tcane. For efficient electricity cogeneration facilities, the cost is, at least, US$ 2,000/kW [22]. Thus, the fixed cost of a traditional sugar mill with an efficient cogeneration plant is US$ 120/tcane. Considering typical shortage of capital in developing countries, it is quite realistic to assume that an eventual carbon tax received by the ethanol sector will be used to support the installation of efficient cogeneration schemes. Low cost financing (compared with regular private financing) is available for potential sugar cane investors. Usually, 80% of the total investment can be financed at an interest rate of 3%/yr above inflation. Thus, to construct a new mill, investor’s equity is equal to US$ 22/tcane. Taking into account the carbon tax of US$ 9.45/tcane, based on US$ 30/tCO₂, and assuming that our scenario implies in linear expansion on the number of efficient sugar mills during the years, carbon tax revenues are enough to cover investments after 3 yrs. To process 60 Mha of harvested sugar cane 20 yrs from the start of the project, annual new installation capacity of 3.0 Mha is required. This figure translates in 270 Mtonnes of new sugar cane capacity addition in mills, requiring an investment of US$ 32.4 billion, from which equity represents US$ 6.48 billion. As discussed in the previous paragraph, such disbursement is only necessary for the first 3 yrs, totaling US$ 19.44 billion, in case an eventual US$ 30/tCO₂ is paid to ethanol producers.

Average gasoline price to final consumers in Brazil is around US$ 1.10/L, which implies in a competitive ethanol price at US$ 0.77/L, since 1 L of ethanol displaces 0.7 L of gasoline [15]. Taxes and supply chain services and revenues represent half of the gasoline price [38], and 35% of the ethanol price. Gasoline price at the refinery is around US$ 0.45/L [39], while ethanol, at mills’ gate is, also, US$ 0.45/L [15]. Considering sugar mills with efficient power plants, investment equals to US$ 120/tcane, and investment share in the cost composition of ethanol is US$ 0.12/L, adding up to US$ 0.48/L. However, efficient cogeneration installations allow for sales of 268 kWh/tcane. Such surplus electricity is being commercialized, through public sales, at a value of US$ 60/MWh - the average price in the period 2005-2018 [40]. Consequently, electricity generates gross revenue of US$ 16.10/tcane instead of US$ 2.40/tcane for low efficiency cogeneration facilities. Even considering operational and maintenance cost increase due to the additional electricity sold, such expenses earlier limited to 50% of the sales price (US$ 1.20) are unlikely to be much higher. Thus, we have assumed an upper limit of US$ 3.00 for these costs. Another cost not yet accounted for deals with eucalyptus acquisition. A good
As shown in detail on Box 3, increasing electricity generation in sugar mills is economically feasible and contributes for achieving negative emissions when ethanol is produced. Such negative emissions are consequence of displacement of natural gas based electricity by bioelectricity generated from sugar cane wastes. Natural gas based electricity is considered as the most likely feedstock to expand electricity supply due its low cost compared with other options, allied to its capacity to offset intermittence of some renewable energy sources. Furthermore, bioelectricity GHGs emissions is low since practically only non-CO$_2$ GHGs have to be accounted when using sugar cane wastes. Exception is the CO$_2$ emitted for transportation of the wastes usually left in the field. Considering that our scenario relies in the use of fast growing trees, their lifecycle GHGs emissions must be accounted for [37], but as previously assessed [16], [7], [6] such emissions are lower than for food crops used for fuel ethanol production.

Hydrous ethanol (92% pure) is sold in Brazil to final consumers, in producing regions, by 70% of the gasoline price and competes with gasohol (27% anhydrous ethanol and 73%).

6. Flexfuel ethanol plug-in hybrids “versus” battery cars
LDV manufactures are investing time and money to develop electric vehicles (EV). There is public expectation by consumers to see EV costs competitive to conventional internal combustion engine (ICE) cars in the near future.

However, forecasts for future battery cost are optimistic [8] and there are reasons to question them. Most of the presently available electric cars (battery or hybrid) are medium to large size units in order to improve competitiveness with conventional ICE cars. The global market size for such cars is 75% [42]; thus, 25% of the global fleet was not technically challenged by electric cars yet. All commercial batteries, including new and old types, have finite lifetime and require replacement during the operational lifetime of the vehicle. Low cost cars can be acquired by US$10,000 and the addition of 80 kWh batteries in these models would add around US$8,000 in the price, even at an optimistic cost of US$ 100/kWh [8]. Even considering potential reduction in the final price due to simplification of the driving train there is little room to offset the significant battery value. Adding to this issue, replacement of the complete set of batteries after 6 to 8 years in such kind of car there is a risk that such investment be incompatible with the value of the used car.

Batteries with 80 kWh or more capacity require special equipment to be fully charged even in a period of 6 hrs. With 220 V, and a current of 50 A some 10 kWh/h can be accumulated in the battery, requiring, at least 8 hrs to full charge. In most countries, residential supply is limited to 220 V/30 A. Thus, overnight connection to the grid is unfeasible for full charge. The same is true if the intention is to use any available power outlets in most of the working places. Even noting that full charge is not required every day, car owners may want to be always prepared for long distance drive as they got used to it with conventional cars. New infrastructure will be required to face present home power limitations and consequently this expense will have to be added to the battery electric car cost. From the other side, plug-in hybrid cars batteries are used for short distance travels inside the city, with 10 times lower electricity storage capacity, demanding around 1500 kWh/yr, a modest value compared with present house consumption.

**Box 3 – Continuation**

figure for this biomass is around US$ 30/t [41]. Considering eucalyptus use is 7.18% of the sugar cane mass, its cost is calculated as equivalent to an increase of US$ 2.15/t cane. Adding up these two costs a value of US$ 5.15/t cane has to be discounted from the gross revenue of US$ 16.10. As a result, electricity sold by sugar mills with efficient cogeneration schemes provides better net revenue to sugar cane owner (US$ 10.95) than low efficient ones (US$ 1.20). Thus, this gain (US$ 9.75/t cane) offsets losses due higher cost of ethanol caused by increase of investment in sugar mills with high efficiency cogeneration schemes that increase ethanol cost by US$ 0.03/L or US$ 2.58/t cane.

As shown in detail on Box 3, increasing electricity generation in sugar mills is economically feasible and contributes for achieving negative emissions when ethanol is produced. Such negative emissions are consequence of displacement of natural gas based electricity by bioelectricity generated from sugar cane wastes. Natural gas based electricity is considered as the most likely feedstock to expand electricity supply due its low cost compared with other options, allied to its capacity to offset intermittence of some renewable energy sources. Furthermore, bioelectricity GHGs emissions is low since practically only non-CO$_2$ GHGs have to be accounted when using sugar cane wastes. Exception is the CO$_2$ emitted for transportation of the wastes usually left in the field. Considering that our scenario relies in the use of fast growing trees, their lifecycle GHGs emissions must be accounted for [37], but as previously assessed [16], [7], [6] such emissions are lower than for food crops used for fuel ethanol production.

Hydrous ethanol (92% pure) is sold in Brazil to final consumers, in producing regions, by 70% of the gasoline price and competes with gasohol (27% anhydrous ethanol and 73%).
Another aspect is the poor GHGs emissions performance of such cars compared with our proposed solution that includes bioelectricity generation and BECCS. Electricity CO\textsubscript{2} average emission at global level is at least 400 g CO\textsubscript{2}/kWh [43] and [44]. Thus, driving a battery car for 15,000 km/yr with a real driving performance of 4.8 km/kWh requires 3,125 kWh plus some losses in the charging process. Probably the value will approach 3,700 kWh, yielding an emission of 1,480 kgCO\textsubscript{2}/yr. Compared with conventional ICE cars with average real driving performance of 10.4 km/L, consuming 1440 L of gasoline, which translate in an annual emission of 4,608 kgCO\textsubscript{2}/yr, the result is quite good. For the flex fuel plug–in hybrid car with negative emission of 74.5 gCO\textsubscript{2}/MJ (100-174.5), with a performance of 15.5 km/L of ethanol (22.3 km/L gasoline X 0.7), consuming 435.5 L/yr, there is a removal of 681.4 kgCO\textsubscript{2}/yr from atmosphere. The difference in GHGs emissions between battery and ethanol plug-in hybrid car is 2,161 kgCO\textsubscript{2}/yr, which has an environmental annual value of US$ 64.8 at a C tax value of US$ 30/tCO\textsubscript{2}. That is, in a fair competitive world with the main purpose to reduce GHGs emissions, owner of battery cars should pay this annual amount. The figure sound quite small, but let us remember that a C tax of US$ 9.45, as already discussed above, is enough to restrain investors equity disbursement to only 3 years; the US$ 64.8, if transferred to investors aiming to supply fuel to the more sustainable ethanol plug-in hybrid cars fleet, means that no equity disbursement from them is necessary to initiate our 1.0 or eventually 1.6 billion flex fuel plug-in hybrid scenario.

Ethanol fuel from sugar cane has been used to power ICE cars from the very beginning of the automotive industry and in modest scale, but since 1975, it become a well known alternative for gasoline due its large-scale use in Brazil. By the end of the last century, its popularity increased further through its large production from corn and use in United States. Since that time, more than 30 countries started to use ethanol as a fuel [45]. The other important technology– bioelectricity generation through steam turbines is, also well established worldwide for more than one century. Finally, BECCS has been introduced at the beginning of this century [46]. In addition, electric vehicles with good performance came into the market at the beginning of this century, after some unsuccessful attempts at the beginning of the 20th century.

Thus, it is worthwhile to search for explanations about the battery car high interest in the last few years in detriment of a proved technical and economic solution based in ethanol.

Ethanol economic and environmental feasibility is clearly demonstrated when derived from sugar cane. Other feedstocks, except maize, face economic barriers. Maize has been an economic success in USA, a very rich country where money has low cost and an excellent logistic infrastructure, but its environmental performance is inferior to sugar cane [16]. Maize has been selected as the feedstock for ethanol since sugar cane is a tropical crop. Even so, sugar cane is cultivated in the South of United States but due climate conditions, the harvesting season is around 4 months. As we discussed in item 4), duration of harvesting season has important economic impacts. Maize has short harvest season but can be stored for years without losing its most important ethanol feedstock that is starch. Sugar cane, on the contrary, once harvested, loses sugar, which is the direct ethanol feedstock, in few days. On the contrary, long life starch is only converted to sugar at the day it will be processed in ethanol. The major lesson from these considerations is that sugar cane has obvious better conditions to compete in cost with maize but makes sense to grow only in tropical countries. In reality, sugar cane is grown in 95 countries, mostly sited in the tropics [25]. In conclusion, sugar cane ethanol is an exclusive product from tropical, and consequently, developing countries. This fact has several consequences: 1) further technological progress in the sugar cane industry must be developed, mainly, by developing countries; 2) know-how and research facilities are available in much larger scale in rich countries; 3) money cost in developing countries are higher than in the rich ones, creating obstacles to endogenous initiative; 4) rich countries economy rely on modern technology to grow, implying in low interest to compete in areas where most of the knowledge is public available ; and 5) new technologies are, usually, less demanding in human labor, as opposed to the traditional ones that creates large number of jobs, making rich countries uncompetitive due their high labor cost.

All these statements do not necessary means that developed countries are wrong, if the objective is their own economic development. The negative aspect comes when exploring new technologies under
the argument of minimizing a global problem, as is the case of climate change. Global problem mitigation that will be paid by all requires solutions at minimum cost.

7. Conclusion
Reduction of GHGs emissions in the transport sector is becoming a reality due to the use of electricity to displace fossil fuels. There are many technological variations, but cost and magnitude of all variations are not fully discussed by experts (as an example, the ETP, an annual IEA publication does not refer to the scenario we propose in this paper). This paper presents details of an old technology that once complemented with the modern transportation approach based on electricity, and deployment of low cost BECCS from CO₂ produced by ethanol processing, has many merits and advantages. We show that 1st. generation ethanol from biomass coupled with modest amount of electricity storage in batteries, as occurs with hybrid plug-in cars, can achieve significant climate change mitigation at no extra cost to society. The paper refers several times to C tax since it can facilitate the proposed pathway to flexfuel plug-in hybrid cars, increasing investor's financial gain. Nevertheless, the conclusion is that such pathway is cost effective independent of any tax. The only exception is for implementation of BECCS facility to avoid dumping CO₂ from sugar fermentation in atmosphere, where a US$ 30/tCO₂ is considered. Electricity use in the transport sector and CCS technologies are well established and can be used immediately. Ethanol from sugar cane is already grown in almost one hundred tropical countries, and the technology and finance procedures to increase its productivity and lower cost are available and can be adopted without paying for royalties from other countries that achieved such target. Temperate countries, through commercial trade, can also have access to the fuel, which due the plurality of potential suppliers is a commodity. Such trade has a modest economic value, as has been discussed, since the global renewable market relies in 60 Mha of sugar cane plantation. In such area a little more than 2,000 Mbbo/yr of gasoline equivalent ethanol can be produced and distributed all over the world to feed, at least, 1 billion cars. Due the high value contribution of the electricity generated from sugar cane wastes complemented by fast growing trees, like eucalyptus, the opportunity is more appropriate for tropical countries, but does not prescribes commercial interest of temperate countries due the possibility of using other well established clean energy sources for the generation of the required complementary electricity demanded by hybrid cars.

Another finding deals with the competition with neat electric cars using large batteries set. Such solution is environmentally inferior to our proposal, mainly in the context of GHGs emissions. It is presently costlier and uncertain regarding future cost, and consequently acceptance by society. Development of this new technology is being performed under the umbrella of sustainable development, which is also valid for the ethanol fuel plus bioelectricity and BECCS pathway.

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