Ethanol Production in Brazil: Bridging its Economic and Environmental Aspects

By Marcos Watanabe*

Overview

Global discussions involving the enhancement of renewable energy use frequently highlight the European Union "Triple 20" deal as the main large-scale effort aimed at changing the worldwide pattern of fossil fuel consumption to power economic activities. Actually, the targets of carbon emissions reduction and increase in the use of renewable energy before 2020 symbolize an extraordinary attempt to achieve more sustainable energy production in the European Union. Fortunately, reactions like this are also being noticed in Asian, African and American countries where the development of new technologies are incrementing the competitiveness of some ventures focused on renewable energy production. In order to understand the potential of renewable energy use outside the European Union, this article will focus on Brazilian biofuel production. Moreover, a few indices derived from Emergy methodology comparing the environmental and economic performances of some biofuel and fossil fuel options observed in some case studies around the world, will also be shown.

Ethanol Production in Brazil

Among biofuels used in the transport sector, Brazilian ethanol is the one that is currently in the spotlight because it's already produced in large quantities and presents competitive prices when compared with gasoline. In 2008, the Brazilian Sugarcane Association stated that ethanol internal demand was of 20 billion liters, the value of which, remarkably, surpassed gasoline consumption in Brazilian light-vehicles (UNICA, 2008). According to the Brazilian Bank for Economical and Social Development (BNDES, 2008), the low price of ethanol production is responsible for this successful achievement. Many studies estimate that costs are between US$ 0.25/liter and US$ 0.30/liter (including all inputs and factors), which would correspond to an oil price of between US$ 36/barrel and US$ 43/barrel. This estimate assumes gasoline prices are 10% higher than crude oil prices in terms of volume and that substitution with anhydrous ethanol is done on a one-to-one volume. Under such conditions, substitution of gasoline with bioethanol is patently viable, but a more complete confirmation of the advantage of this biofuel can be seen by comparing plant prices prior to taxation (BNDES, 2008).

The fortunate experience of ethanol use in Brazil may also be coupled with a superior sucrose yield and a higher potential of biomass production of sugarcane – an average of 87 tons per hectare in South Central Brazil – than observed in other crops. As Figure 1 shows, only beets can be compared with sugarcane in terms of ethanol production per cultivated hectare. However, the industrial process of ethanol production from beets depends on an external power input (electricity and fuel) while sugarcane electricity is provided by bagasse burning at the mill. Moreover, as biotechnology of enzymes is improved, ethanol from sugarcane cellulosic residue probably could increase average productivity to 9,000 liters per hectare (BNDES, 2008).

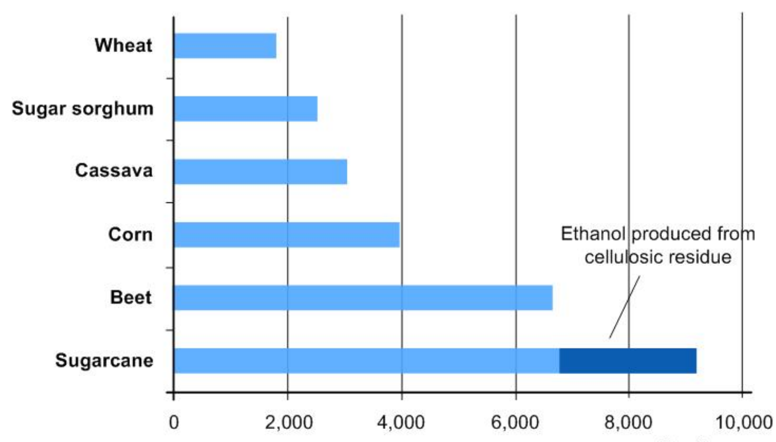

Figure 1. Average ethanol productivity per area for different crops. Source: BNDES (2008)

Ethanol Benefits: Less Greenhouse Gases and Improved Energy Ratio

Among the possible benefits derived from ethanol use in the replacement of gasoline consumption, researchers highlight the reduction of carbon dioxide emissions. According to Macedo et al. (2008), ethanol production is responsible for an average emission of 440 kg of CO_2 equivalents per cubic meter of ethanol, when it is blended with gasoline (usually 25 % in Brazil). Net avoided emis-

* Marcos Watanabe is the IAEE Student Council Representative for 2009 and 2010. As PhD student at University of Campinas, Brazil, his research focuses on the assessment of the environmental and economical impacts of sugarcane ethanol production.

sions can reach 1,900 kg CO_2 equivalents per cubic meter of ethanol used. Considering such production simultaneously with electricity generation by residue burning, it is estimated that every 100 million tons of sugarcane avoids 12.6 million tons of CO_2, and this represents an important greenhouse gas emissions reduction (BNDES, 2008; UNICA, 2007). Such performance (see Table 1) disregards land-use change in the case of cropland area expansion overtaking ecosystem areas. According to Searchinger et al. (2008), if rainforests were converted to cropland, a pay-back time of 45 years would probably be necessary to neutralize all emissions generated by such ecosystem destruction.

Another strong aspect of Brazilian ethanol is the energy ratio. Including production of chemical and materials, feedstock growth, transportation and processing, Macedo et al. (2008) have quantified that for 1 ton of sugarcane, a total fossil input of 233 MJ produces 2185 MJ of ethanol, bagasse surplus and electricity. In this case the energy balance would be approximately 9. Table 1 shows energy ratios obtained for different feedstock.

Feedstock	**Energy Ratio**	**CO_{2eq} avoided**
Sugarcane	9.3	89%
Corn	0.6-2.0	-30% to 38%
Wheat	0.9-1.1	19% to 47%
Beet	1.2-1.8	35% to 45%
Cassava	1.6-1.7	83%
Lignocellulosic residues	8.3-8.4	66% to 73%

Table 1. Comparison of different feedstock for biofuel production

Source: BNDES (2008).* Theoretical estimate, process under development.

In spite of the innumerous economic and environmental benefits derived from ethanol consumption, biofuel production can also generate undesirable effects depending on its agricultural model of production. Using economic language, modern agricultural production can also generate negative externalities, usually related to soil erosion, damage to wildlife, air and water pollution and others (Pretty et al. 2000). Considering that these tradeoffs can give rise to financial and environmental costs, more accurate assessment is sometimes required to ensure that biofuel production is feasible in economic and environmental aspects. In order to quantify such performance, the Emergy approach can be considered a useful tool because it puts economic and environmental systems on the same basis.

Emergy Approach to Connect Environmental and Economic Systems

All systems, natural or man-made, depend on inputs to produce something. All products or services produced by systems have “emergy”. Emergy means “energy memory” or “the available required energy used up directly and indirectly to make a service or product” (Odum, 1996). The Emergy approach converts all energy, mass and money flows of a certain production system into a same energy basis. Instead of tons of oil equivalent (toe), this methodology uses the solar energy equivalent joules (seJ) as standard. In summary, every product or service can be quantified in terms of seJ. Although it is universal, this methodology is particularly important to deal with renewable energy systems because it has the capacity of including the natural contributions such as sunlight, rain, wind, geothermal energy and others in order to generate biomass.

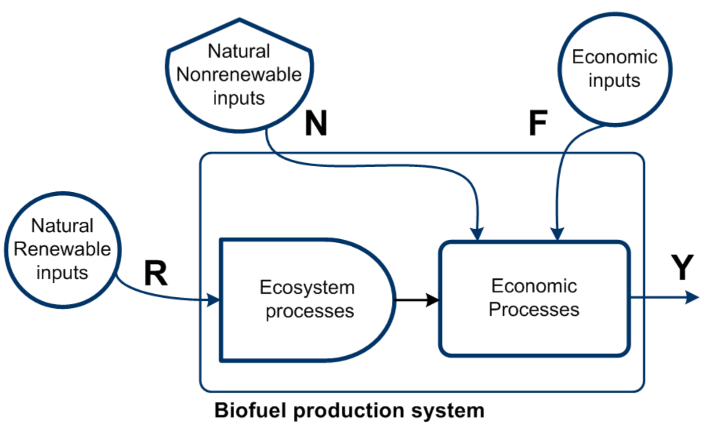

Figure 2. Simplified view of a production system according to the Emergy approach.

The Emergy approach distinguishes three main input categories: Environmental Renewable inputs (R) such as sunlight, wind, rain, etc.; Environmental Non-Renewable Inputs (N) such as soil, groundwater, fossil fuels, etc.; and Material and Services from the economy (F) such as human labor, electricity, construction and others. The output can be a product or service which contains the total Emergy (Y). Such considerations makes the Emergy approach a great tool to measure and compare the economic and environmental indices of different systems.

Four indices derived from the Emergy approach are important to assess biofuel production:

- **Transformity (Tr)** is equal to the emergy content (Y in solar equivalent joules) divided by total energy content (given in joules or calories). The higher the value, the lower the system’s efficiency.
- **Renewability (%R)** is equal to the Renewable Input (R) divided by total emergy (Y). This index quantifies the percentage of renewable energy (sun, wind, rain, etc.) used up in the production process. The higher the value, the greater the sustainability of the production system.
- **Emergy Yield Ratio (EYR)** is equal to the total emergy (Y) divided by total economic inputs (F) such as human labor, machinery, fertilizers and others. It reflects the ability of a certain system to deliver energy to the economy by amplifying its investment. The higher the value, the lower the

system's dependence on economic investment and the higher the enterprise competitiveness.

- Emergy Loading Ratio (ELR) is equal to Non-renewable resources from the economy and environment (F+N) divided by Renewable Input (R). It is a general measure of the environmental impact of a production system. The lower the value, the lower the environmental stress.

Emergy Indices to Compare Different Fuel Alternatives

Considering Brazilian ethanol, Transformity indices have ranged from 50,000 to 100,000 sej/J, while gasoline values have ranged from 65,000 sej/J to 110,000 sej/J. As Table 2 shows, Brazilian ethanol has presented the same Transformity magnitude of fossil fuels in these cases, which means the same level of efficiency in terms of emergy invested to the amount of emergy delivered. However, other biofuel options have presented higher Transformity indices, which means lower efficiency processes.

Energy Source	Transformity (sej/J)	Reference
Natual gas, world average	8.04 E+04	Odum (1996)
Oil, world average	9.05 E+04	Odum (1996)
Gasoline, world average	1.11 E+05	Odum (1996)
Gasoline, Italy	6.60 E+04	Bastianoni et al. (2009)
Sugarcane ethanol, Brazil	5.30 E+04	Pereira(2008)
Corn ethanol, U.S.	1.00 E+05	Ulgiati (2001)
Sugarcane ethanol, U.S.	1.40 E+05	Bastianoni & Marchetini (1996)

Table 2. Transformity indices among various energy sources.

Fossil fuels (oil, natural gas and gasoline) have better Transformity indices because such natural stocks were produced millions of years ago by natural processes. If ventures have abundant and well-positioned storage, relatively lower effort is necessary to extract and refine them compared with other sources of energy. In the case of biofuel production, crops are produced and processed in just one year and demand relatively more emergy investment per emergy delivered. Moreover, factors like high diesel use in machines, increasing fertilizer inputs and loss of topsoil in the agricultural stage can negatively affect the efficiency of other biofuel production alternatives.

Assessing the Emergy Yield Ratio (EYR) indices, it is possible to quantify the system's reliance on economic investment. In theory, the minimum value for EYR occurs when the quantity of emergy delivered by the system is equal to the emergy within the economic investment; in this case, EYR would be 1. For such a system, EYR=1 would indicate zero ability of capturing free local resources in the environment and also extreme dependence on economic investment to deliver energy. As table 3 shows, the highest EYR values are observed for fossil fuel production systems, indicating higher economic competitiveness compared with biofuel production systems. Such a difference is explained again by the timescale necessary for fossil fuel formation and accumulation. For fossil fuels, previous emergy "investment" has been made by natural processes during millions of years; in the case of biofuel, more economic investment would be required. It would occur because biomass has a short production timescale (usually one year) and also has low "previous inputs" made by the surrounding environment. As a consequence, biofuel production demands more economic investment and can be less competitive than recent fossil fuel production.

Energy Source	EYR	Reference
Coal	10.5	Odum (1996)
Natual gas	10.3	Odum (1996)
Diesel and gasoline	8.4	Odum (1996)
Sugarcane ethanol, Brazil	1.57	Pereira (2008)
Sugarcane ethanol, U.S.	1.17	Bastianoni & Marchetini (1996)
Corn ethanol, Europe average	1.08	Ulgiati (2001)

Table 3.
EYR indices among various energy sources.

Another fundamental index to assess sustainability is Renewability (%R). Emergy analysis shows that certain energy production systems considered as "renewable" don't have a complete renewable character and rely upon some non-renewable inputs. As table 4 shows, fossil fuels such as coal, diesel, gasoline and natural gas are completely non-renewable, which means 0% renewability since their rates of extraction are thousands or millions of times superior to their rate of production by natural processes. However, less obvious results are shown with Brazilian sugarcane ethanol, U.S. sugarcane ethanol and European corn ethanol where values correspond to 35%, 14.2% and 5.4%, respectively. European Corn ethanol's performance of 5.4% Renewability indicates that 94.6% of all inputs used up in corn ethanol production came from non-renewable inputs. Such performance is mainly affected by the degree of soil erosion, fertilizer application, mechanization, diesel consumption, and other factors.

Energy Source	Renewability	Reference
Coal	0%	Odum (1996)
Natual gas	0%	Odum (1996)
Diesel and gasoline	0%	Odum (1996)
Sugarcane ethanol, Brazil	35%	Pereira (2008)
Corn ethanol, Europe	5.4%	Ulgiati (2001)
Sugarcane ethanol, U.S.	14.2%	Bastianoni & Marchetini (1996)

Table 4.
Renewability indices among various energy sources.

Finally, the Environmental Loading Ratio (ELR) is important to measure environmental stress caused by energy production systems and it would be mainly applied to agro-ecosystems. The best value would be zero, meaning zero ecosystem disturbances. According to Brown & Ulgiati (2004), values ranging from zero to 2 would indicate a moderate level of environmental impact, but values superior to 10 would indicate high environmental stress. As presented in table 5, soybean biodiesel and sugarcane ethanol production in Brazil have better performance than ethanol produced in other systems presented in this paper. As table 5 shows, Brazilian agro-ecosystems and mills cause moderate stress on the environment, three times inferior to those systems studied in other parts of the world. However, such results don't include the land-use-change negative impacts when cropland systems eliminate ecosystems. ELR only measures the pressure on the environment derived from the temporary pattern of agricultural management. Moreover, Pereira (2008) and Cavalett (2008) affirmed that the agricultural stage causes more impact on the environment than the processing and transportation stages. Because of that, they recommend that such energy production systems should focus on land practices in order to improve their performances.

Energy Source	ELR	Reference
Sugarcane ethanol, Brazil	2.34	Pereira (2008)
Sugarcane ethanol, U.S.	6.04	Bastianoni & Marchetini (1996)
Corn ethanol, Europe	7.42	Ulgiati (2001)
Soybean biodiesel Brazil	2.26	Cavalett (2008)

Table 5.
Comparison of ELR indices among various energy sources.

Conclusions

Among biofuel alternatives in this paper, Brazilian ethanol had a very satisfactory performance. Of course, results can vary depending on the region of production and, consequently, more local research using emergy methodology would be necessary to enhance the quality of the discussion. Although fossil fuel production systems require less economic investment to deliver one unit of emergy (high EYR), biofuel systems have higher sustainability performances (higher %R) and could contribute to sustainable development depending on the model of production and land practices. Nevertheless, eventual benefits generated to the economy and environment from biofuel production may be drastically reduced when cropland area expansion leads to ecosystem elimination. Analogously to the carbon balance assessment made by Searchinger et al. (2008), the destruction of such natural systems (rainforests, for example) could result in a long pay-back time to mitigate the negative externalities related to the loss of a variety of goods and services provided by natural systems.

References

BNDES. Banco Nacional de Desenvolvimento Econômico e Social (2008): Sugarcane-based bioethanol: energy for sustainable development / coordination BNDES and CGEE – Rio de Janeiro : BNDES. 304 p.

Bastianoni, S., Campbell, Ridolfi, R., Pulselli, F.M. (2009): The solar transformity of petroleum fuels. Ecological Modelling v.220 p.40-50.

Bastianoni, S., Marchetinni, N. (1996): Ethanol production from biomass: Analysis of process efficiency and sustainability. Biomass and Bioenergy, v. 11, 5 p. 411-418.

Cavalett, O. (2008): Análise de ciclo de vida da soja (title in English: Soybean life cycle assessment). State University of Campinas, Brazil. Data available in: <www.unicamp.br/fea/ortega/extensao/extensao.htm>

Macedo, I.C., Seabra, J.E.A., Silva, J.E.A.R (2008): Greenhouse gases emissions in the produciton and use of ethanol from sugarcane: the 2005/2006 averages and prediciton for 2020. Biomass and Bioenergy, doi:10.1016/j.biombioe.2007.12.006.

Odum, H.T. (1996): Environmental Accounting. Emergy and Environmental Decision Making. J.Wiley & Sons. NY.

Pereira, C.F. (2008): Avaliação de sustentabilidade ampliada de produtos agroindustriais. Estudo de caso: laranja e etanol. (title in English: Sustainability evaluation of agro industrial products. Case studies: orange juice and ethanol). State University of Campinas, Brazil. Data available in: <www.unicamp.br/fea/ortega/extensao/extensao.htm>

Pretty, J.N. et al. (2000): An assessment of the total external costs of UK agriculture. Agricultural Systems 65, 113-136.

Searchinger et al. (2008): Use of U.S. Croplands for biofuel increases greenhouse gases through emissions from land-use change. Science 29, v.319., no.5867, pp. 1238-1240.

Ulgiati, S.(2001): A comprehensive energy and economic assessment of biofuels: when "green" is not enough. Critical Reviews in Plant Sciences, v. 20, p. 71-106.

UNICA. Sugarcane Industry Association (2007, 2008). Data available in <www.english.unica.com.br>