The challenge of biofuels

José Goldemberg*

DOI: 10.1039/b814178a

Currently two types of biofuels are being used in significant amounts around the world: ethanol and biodiesel. Ethanol is produced in large amounts from maize in the United States, sugarcane in Brazil and in smaller amounts from wheat and sugar beet in Europe. Biodiesel is produced predominantly from rapeseed in Europe, palm oil in Asia and soybeans in Brazil.

Ethanol and biodiesel are mainly used blended with gasoline or diesel, respectively, in low proportions (smaller than 10%). High proportion blends and ethanol used in pure form in adapted vehicles are used in Brazil, as are flex-fuel cars which accept any blend of ethanol and gasoline.[1]

On technical grounds biofuels are a good alternative to gasoline and diesel oil.[2] They are produced from agricultural products and do not have the impurities petroleum products have such as sulfur oxides and particulates, the main source of pollution in large metropolitan areas. Replacement of gasoline by ethanol from sugarcane in Brazil has resulted in very significant improvements to the air quality of São Paulo over the last 15 years.[3] In addition, on a life cycle basis, if proper feedstock and agricultural practices are used, they also reduce greenhouse gas (GHG) emissions.[4]

Institute of Electrotechnics and Energy, University of São Paulo, São Paulo, Brazil. E-mail: goldemb@iee.usp.br

The volume of ethanol, as a fuel replacing gasoline is presently around 500 000 barrels of oil equivalent per day or 0.7% of the world's oil consumption of 86 million barrels per day. Ethanol is produced mainly in the United States (from corn) and in Brazil (from sugarcane). In 2006, the US produced 18.5 billion liters,[5] Brazil 17.8 billion liters[6] and the European Union 1.55 billion liters[7] (mainly from sugar beet) making a grand total of 37 billion liters per year. The land in use for ethanol production in 2006 in the US (from maize) was 5.1 million hectares and in Brazil (from sugarcane) was 2.9 million hectares.[8]

The amount of biodiesel in use is much smaller *circa* 2 billion tonnes per year mainly in Europe.[7]

The use of ethanol is bound to increase very substantially in the next 10–15 years due to mandates adopted by governments. The recent US Energy Bill sets a target for the production of 15 billion gallons by 2015 of ethanol from corn using current technologies and an additional 21 billion gallons by 2022 from cellulosic materials which require new "second generation technologies" that are still in development. The European Union has adopted a directive requiring 3.9 billion gallons of ethanol by 2020 to replace 10% of the gasoline. Many other countries have already adopted blends of 2% ethanol (E2) or 10% ethanol (E10) in gasoline, among which are Canada, China, India, and Australia, in a number of provinces, others such as Colombia, Argentina, Philippines and South Africa will adopt E2 or E10 by 2010–2012.[9]

It is difficult to know how much ethanol will be needed in these countries but it is estimated at least 1 billion gallons. Brazil already replaces 20–25% of its gasoline with ethanol, and the introduction of flex-fuel cars means *circa* 50% of gasoline is now replaced by ethanol. If the mandates adopted by different countries are met ethanol will replace at least 10% of the gasoline used worldwide by 2022 and the amount of ethanol needed will triple to 30 billion gallons per year, excluding the 21 billion gallons expected to come from cellulosic materials.

Such large demand and the corresponding use of agricultural land needed for its production has as generated a number of objections to the use of biofuels, the main ones being:

I. Competition for land for fuel "*versus*" land for food is causing famine in the world and deforestation of the Amazonia and other tropical forests.

II. On a life cycle basis biofuels do not reduce GHG emissions.

III. Biofuels are only viable in "niches"; the Brazilian experience is unique.

IV. Only subsidized production of biofuels is possible.

It is argued here that such concerns are grossly exaggerated and correspond to a simplistic and frequently skewed interpretation of what is really happening in this field.

Professor José Goldemberg earned his PhD in Physical Sciences from the University de São Paulo in 1954 where he later became a full professor. He was Rector of the University from 1986 to 1990. A member of the Brazilian Academy of Sciences, he has served as the President of the Brazilian Association for the Advancement of Science, as Brazil's secretary of state for science and technology and as minister of state for education. Over the years, he has carried out research and taught at the University of Illinois, Stanford University of Paris (Orsay) and Princeton University. From 1998–2000, he served as chairman of the World Energy Assessment. More recently, between 2002 and 2006, he was secretary for the environment of the state of São Paulo. He has authored many technical papers and books on nuclear physics, sustainable development and energy. He is the recipient of the Blue Planet Prize 2008.

I. Competition for land for fuel "*versus*" land for food is causing famine in the world and leading to deforestation of the Amazonia and other tropical forests

The recent rise in prices for agricultural products, after several decades of declining real prices,[10] is usually seen as one of the causes of famine in the some parts of the world and has given rise to the politically laden controversy of fuel "*versus*" food, which some claim would hard hit the poor and may cause famine.[8] In fact, grain prices have more than doubled since January 2006 with over 60% of the rise occurring since January 2008 following closely the rising price of petroleum; grain prices are now starting to drop as the 2008 crop is harvested.[11] In contrast, the point has been made that higher crops prices will not necessarily harm the poorest people; many of the world's 800 million undernourished people are farmers or farm labours, who could benefit.[12]

To keep a perspective, it is a useful reminder that 93 million hectares of land are used presently for soy production around the world. As a general trend the price of food commodities has been decreasing since 1975 but fluctuations, in the area planted and the price of food commodities (as well as crude oil), are frequent. Such fluctuations have been taking place for many decades due to an enormous number of factors and events.[5] Moreover, not all biofuels have the same impact on food prices – in the case of Brazil, the increased production of ethanol from sugarcane did not induce an increase in sugar prices.[11]

Land already in use for agriculture (arable land) is 1.5 billion hectares and additional land potentially available is 440 million hectares of which 250 million hectares are in South and Central America and 180 million are in Africa. Therefore, the area in use for biofuels is only 0.55% of the land in use and even an order of magnitude growth should not be a very disturbing factor.[13,14]

This problem has been extensively analysed in many reports, particularly from the World Bank,[11] which have pointed out that grain prices have risen due to a number of individual factors, whose combined effect has led to an upward price spiral, namely: high energy and fertilizer prices, the continuing depreciation of the US dollar, drought in Australia, growing global demand for grains (particularly in China), changes in the import–export policies of some countries and speculative activity on future commodities trading, and regional problems driven by policies subsidising biofuels' production in the US and Europe. An example of the effect of such policies is given by the fact that in the US, from 2006 to 2007, corn acreage grew 19% to almost 37 million hectares, *i.e.* by 7 million hectares. Most of this expansion came at the expense of soybean planting which decreased 17% from 31 to 26 million hectares *i.e.* by 5 million hectares.[15] This is approximately 6% of the world area used for that crop contributing to the drive of prices upwards. One should point out that these land use changes have been reversed in 2008.[16] However, the point has been made that to offset this decrease other countries had to expand soybean production possibly in the Amazonia increasing its deforestation.[17] Such a speculative "domino effect" is not borne out by the facts: the area used for soybeans in Brazil (mainly in the Amazonia) has not increased since 2004.[18] The reality is that deforestation in the Amazonia has been going on for a long time at a rate of approximately 1 million hectares per year[19] and that recent increases are not due to soybean expansion but to cattle.[16]

II. On a life cycle basis biofuels do not reduce GHG emissions

There are many studies on this subject and the results are sensitive to assumptions about the use of fertilizers, pesticides and other inputs in the industrial phase of production but a fair estimate is that compared to gasoline, ethanol from maize emits 18% less CO_2 and ethanol from sugarcane, 91% less.[4] The reason for this is that bagasse from sugarcane is used as a source of heat (and electricity) in the preparation of ethanol, including crushing and distillation. In contrast, ethanol from maize requires external energy which in the US comes mostly from fossil fuels particularly coal. In a sense one could say that by using sugarcane one converts the sun's energy through photosynthesis into ethanol and by using maize one converts coal into ethanol.

Emissions from land use changes resulting in massive deforestation could be a source of GHG emissions but the calculations of Fargione *et al.*[20] refer to a worst case scenario which is not presently taking place. This is because the expansion in the area used by biofuels is not taking place in virgin tropical forests with exception of the practice in Southeast Asia where large portions of forest have been replaced by palm trees.[21] Such practice, of course, would release a large amount of CO_2 but extensive studies have been made of CO_2 releases from other agricultural practices that do not involve deforestation with results much less alarming then the one reached by Fargione *et al.*[22,23]

The expansion of sugarcane plantations in Brazil is taking place on degraded pasture located very far from the Amazonia wet tropical forest where sugarcane does not grow well. As proof, one can mention the fact that the average number of head of cattle/hectare was 1.28 in 2001 in the state of São Paulo and this had increased but only to 1.41 in 2005 due to the expansion of sugarcane plantations on former pasture.[3] In the country as a whole cattle density is even lower, closer to 1 cattle/hectare. The deforestation in the Amazonia is linked closely to cattle-breeding for meat production, for internal consumption and for export, and not to ethanol production. Today, Brazil has approximately 200 million head of cattle (on 237 million hectares).

The whole issue of CO_2 emissions from land use changes and agricultural expansion is, in general, not a food *versus* fuel problem, instead it should be called more appropriately a food *versus* climate problem, since it applies to the expansion of agricultural areas in general.

III. Only subsidized production of biofuels is possible

Presently, this is indeed the case for the production of ethanol from corn in the US and from wheat and sugar beet in Europe where production costs are approximately, respectively, two and four times higher than those of ethanol from sugarcane in Brazil,[24,25] where in the last 30 years, thanks to economies of scale and productivity gains of approximately 4% per year, ethanol cost has declined by a factor 3 to become fully competitive with gasoline without any subsidies.[26]

IV. Biofuels are only viable in "niches"; the Brazilian experience is unique

There are almost 100 countries producing sugarcane on an area of 20 million hectares (approximately 0.5% of the total world area used for agriculture). The 15 most important producers account for 86% of the total production of sugarcane.[8] It is easy to convert plants producing sugar to ethanol distilleries and most of the 325 existing plants in Brazil are dual purpose. Only 47% of the sugarcane area in Brazil, *i.e.* 2.9 million hectares, is used to produce ethanol.[6]

It is clear therefore that the production of ethanol from sugarcane could be expanded significantly if, following the example of Brazil, other countries use a fraction of their sugarcane output for ethanol production. Colombia already has four large distilleries in operation and other sugar producing countries, mainly in the Caribbean, have plans for more.[27]

A worldwide increase of 50% in the present 20 million hectares area dedicated to sugarcane, *i.e.* 10 million hectares, would if used for ethanol production (compared to the 2.9 million hectares presently in use in Brazil) by 2022 result in the production of an extra 21 billion gallons of ethanol, which together with US production would more than suffice to meet projected needs. And, carbon emissions will be reduced by approximately 57 million tons per year.[4]

Acknowledgements

I wish to thank Patricia Guardabassi for assistance in preparing this paper.

References

1 J. Goldemberg, *The Brazilian biofuels industry. Biotechnology for Biofuels 2008*, vol. 1, ch. 6, DOI: 10.1186/1754-6834-1-6, http://www.biotechnologyforbiofuels.com/content/1/1/6.
2 J. R. Moreira and J. Goldemberg, The alcohol program, *Energy Policy*, 1999, **27**, 229–245.
3 J. R. Goldemberg, S. T. Coelho and P. M. Guardabassi, The sustainability of ethanol production from sugarcane, *Energy Policy*, 2008, **36**, 2086–2097.
4 J. Goldemberg, Ethanol for a sustainable energy future, *Science*, 2007, **315**, 808, DOI: 10.1126/science.1137013.
5 R. L. Naylor, A. J. Lisha, M. B. Burke, W. P. Falcon, J. C. Gaskell, S. D. Rozelle and K. G. Cassman, *The ripple effect – biofuels, food security and the environment*, 2007, vol. 49, pp. 30–43.
6 *Ethanol production in Brazil-série histórica 1990–2007. (Brazilian ethanol production-time series 1990–2007)*, UNICA (2008) http://www.portalunica.com.br/portalunica/files/referencia_estatisticas_producaobrasil-9-Tabela.xls.
7 *Biofuels in the European Union – A vision for 2030 and beyond*, Biofuels Research Advisory Council, 2006, ISBN 92-79-01748-9; ISSN 1018-5593, pp. 40, http://ec.europa.eu/research/energy/pdf/biofuels_vision_2030_en.pdf.
8 *FAOSTAT (United Nations Food and Agricultural Organization) FAO*2007, http://faostat.fao.org/default.aspx.
9 REN21.2006, *Renewables global status report 2006 update*, Paris: REN21 Secretariat and Washington, DC: Worldwatch Institute, http://www.ren21.net/pdf/RE_GSR_2006_Update.pdf.
10 J. Von Braun, *When foods makes fuel: The promises and challenges of biofuels. Keynote address: Biofuels, energy and agriculture*, 2007, http://www.ifpri.org/pubs/speeches/vonbraun/2007jvbcrawfordkeynote.pdf.
11 *G8 Hokkaido Toyako Summit – Double jeopardy: responding to high food and fuel prices*, World Bank, 2008, http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0/contentMDK:21827681~pagePK:64257043~piPK:437376~theSitePK:4607,00.html.
12 *Biofuels production, trade and sustainable development: policy discussion. Draft paper*, International Centre for Trade and Sustainable Development (ICTSD), Geneva, Switzerland, 2008.
13 R. Doornbosch and R. Steenblik. *Biofuels: is the cure worse than the disease? OECD-Round table on sustainable development*, OECD, Paris, France, September, 2007. http://www.foeeurope.org/publications/2007/OECD_Biofuels_Cure_Worse_Than_Disease_Sept07.pdf.
14 G. Berndes, M. Hoogwijkb and R. van den Broekc, The contribution of biomass in the future global energy supply: a review of 17 studies, *Biomass Bioenergy*, 2003, **25**, 1–28.
15 *North American Crop Update, 2007*, HGCA, 2008, www.openi.co.uk/h070724.htm, posted July 24, 2007; consulted February 11, 2008.
16 *Prospective Plantings*, USDA, National Agricultural Statistics Service, March 3, 2008, http://www.usda.gov/nass/PUBS/TODAYRPT/pspl0308.pdf.
17 W. F. Laurence, Switch to corn promotes Amazon deforestation, *Science*, 2007, **318**, 1721, DOI: 10.1126/science.318.5857.1721b.
18 *Agricultural database*, CONAB (National Supplying Company), Brazil, http://www.conab.gov.br/conabweb/download/safra/BrasilProdutoSerieHist.xls (2006).
19 *Prodes Project-satellite monitoring of Amazon Forest. Annual estimates 1988–2007*, National Institute for Spatial Research (INPE)http://www.obt.inpe.br/prodes/prodes_1988_2007.htm (2008).
20 J. Fargione, J. Hill, D. Tilman, S. Polasky and P. Hawthorne, Land clearing and the biofuel carbon debt, *Science*, 2008, **319**, 1235–1238, DOI: 10.1126/science.1152747.
21 *Greasy palms - The social and ecological impacts of large-scale oil palm plantation development in Southeast Asia*, Friends of the Earth, 2005, http://www.foe.co.uk/resource/reports/geasy_palms_impacts.pdf.
22 Good practices Guidance for Land Use, *Land-Use Change and Forestry 2003*, ed. Jim Penman, Michael Gytarsky, Taka Hiraishi, Thelma Krug, Dina Kruger, Ritta Pipatti, Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe and Faian Wagner, Institute for Global Environmental Strategies (IGES) for the IPCC, Intergovernmental Panel on Climate Change (IPPC), ISBN 4-88788-003-0, 2003.
23 C. E. P. Cerri, M. Easter, K. Paustian, K. Killian, K. Coleman, M. Bernoux, P. Fallon, D. S. Powlson, N. H. Batjes, E. Milne C. C. Cerri, Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030, *Agriculture, Ecosystems and Environment*, 2007, vol. 122, pp. 58–72.
24 O. Henniges and J. Zeddies, Economics of Bioethanol in the Asia-Pacific: Australia - Thailand - China in *F. O. Licht's World Ethanol and Biofuels Report*, ed. F. O. Licht, Tunbridge Wells, UK, 2005, vol. 3, (No. 51).
25 *Biofuels for Transport: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century*, Worldwatch Institute, Washington DC, ISBN 978-1-84407-422-8, 2006.
26 J. Goldemberg, S. T. Coelho, O. S. Lucon and P. M. Nastari, Ethanol learning curve-the Brazilian experience, *Biomass Bioenergy*, 2003, **26**, 301–304.
27 L. A. H. Nogueira, *Biocombustíveis na América Latina: situação atual e perspectivas*, Fundação Memorial da América Latina, São Paulo, Brazil, ISBN 978-85-85373-75-7, 2007.