Recent developments in the world of biofuels: Spring 2010

Indirect land use change (iLUC) has become a major biofuels topic, ever since Searchinger *et al* (2008)[1] pointed out that calculations of potential greenhouse gas (GHG) savings through adoption of biofuels had not taken into account the effects caused by the crops displaced by biofuels. These crops have to be grown somewhere and if this involves deforestation for instance, then any GHGs released to replace crops must be taken into consideration. Since that paper there has been a vigorous response from the biofuel lobby, and considerable debate about the validity of the Searchinger approach.

A part of the debate is about the assumptions made, including the different views on yields and how they will improve or not, in the years to come. Industry tends naturally to be optimistic; scientists on the other hand base their predictions on current evidence and hence will give a more measured outlook. The recent paper by Johnston *et al* (2009)[2] is in this tradition, since their detailed study suggests that yield tables and estimates generally used to calculate biofuel feasibility are wildly optimistic, by between 100 to 150% of the authors' best estimates. They encourage practitioners to use regionally-specific data for future biofuel studies, and take the lead on this by covering results for 20 feedstock crops from 238 countries, states, territories and protectorates. So far we have not seen the same degree of outcry to this paper as to Searchinger *et al's* paper, but the implications are nevertheless serious. It recalls Searchinger's (2009)[3] remark: "*A kind of reverse Murphy's Law in effect creeps into biofuel papers; if anything can go right it will.*"

Searchinger himself has vigorously defended his iLUC position and newly published papers are tending to support him. Lapola *et al.* (2010)[4] for instance have looked at potential land-use changes from biofuel expansion in Brazil. "*To fill the biofuel production targets for 2020, sugarcane would require an additional 57,200 sq km and soybean an additional 108,100 sq km of land. Roughly 88% of this expansion (145,700 sq km) would take place in areas previously used as rangeland,*" say the authors. Their simulations suggest that direct deforestation would mean destruction of a fairly modest 1,800 sq km of forest and 2,000 sq km of woody savannah in the case of soybean. However, their models also suggest that large areas of rainforest and cerrado (savannah) would be indirectly impacted as displaced cattle ranchers find new lands to exploit.

When it comes to carbon payback times, the authors found that 4 years would be needed to compensate for direct emissions from conversion for cane relative to emissions from fossil fuels and 35 years for soy biodiesel. But factoring in iLUC — cattle ranching displaced to forest lands by cropland expansion — dramatically extends the amount of time needed for emissions savings from biofuel production to compensate for emissions from deforestation: by 40 years for sugarcane ethanol and 211 years for soy biodiesel.

"*Indirect land-use change could considerably compromise the GHG savings from growing biofuels, mainly by pushing rangeland frontier into the Amazon forest and Brazilian Cerrado*

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[1] Searchinger T (2008) www.sciencexpress.org / 7 February 2008 / Page 3 / 10.1126/science.1151861

[2] Johnston M, Foley J A, Holloway T, Kucharik C, Monfreda C (2009) Resetting global expectations from agricultural biofuels. Environmental Research Letters 4, 1-9.

[3] Searchinger T (2009) The impacts of biofuels on greenhouse gases: how land use change alters the equation. German Marshall Fund Policy Brief. 8pp.

[4] Lapola DM, Schaldach R, Alcamo J Bondeau A Koch J, Koelking C, Priess JA, (2010) Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Published online before print February 8, 2010, doi: 10.1073/pnas.0907318107

savanna," Lapola and colleagues write. The authors suggest that planting oil palm instead of sugarcane or soy on pasture lands would result in some direct deforestation (300 sq km) but significantly reduce emissions from iLUC due to the crop's substantially higher oil yield.

Another paper by Yan *et al.* (2010)[5] also finds worrying iLUC implications. They review 'well-to-wheel' energy use and GHG emissions of biofuels in the US and China and conclude that, after iLUC is taken into account, GHG emissions for E-10 sorghum, maize and wheat are much higher than gasoline, whereas cassava and sugarcane are more favourable than fossil fuel if the feedstock is grown on grassland but not if it is from deforested land. B-20 soybean would have the highest GHG emissions among all the biofuel blends considered—and any GHG benefits for B-20 rapeseed and B-20 jatropha would vanish when the feedstocks were grown on deforested land and largely diminish on grassland. (The terms E-10 and B-20 refer to the final mix of biofuel with fossil fuel: E-10 = 10% ethanol/90%petrol; B-20 = 20% biodiesel/80%diesel).

On the subject of Jatropha: two recent stories illustrate the remarkable commercial ups and downs of this crop. An article in Forbes[6] reports that SG Biofuels (a San Diego company) now has a library of jatropha breeds and jatropha DNA from which it has just issued its first commercial product, a variety called "J-Max 100" which produces a yield 100% better than undomesticated jatropha. CEO Kirk Haney says that the new variety produces eight times more oil per acre than soybeans and four times more than rapeseed. It will also yield well, he says, on marginal land that is poor for growing food crops. Haney claims that J-Max 100 can produce fuel at the equivalent of $58 per barrel of oil.

Contrast this with the April 9th Reuter's report[7] on D1 oils, a company with around 200,000 ha of plantations that has been concentrating on jatropha production, including, like SG Biofuels, research on domestication of the plant to improve yields. Reuter reports that talks on renewed financing are unresolved. Options include the sale of the company or a reverse merger. These difficulties have been provoked by a December 2009 statement by major shareholder Principle Capital Fund Managers that the company should immediately seek buyers for its business and that it would vote against any resolution by D1 to raise further equity. Shares of D1 Oils are currently trading at around 4 pence, from a high of 500 pence five years ago.

A new paper from Thailand by Prueksakorn *et al* (2010)[8], adds valuable new data through having conducted a full energy analysis on two different jatropha plantation systems. They calculate that an annual harvest system that includes the wood along with the seeds produces an impressive 7.5 times more energy than consumed, though the oil yield itself accounted for less than 10% of the total energy yield. The implication is that exploited by itself, the oil is energy negative. If this study is widely applicable, it would mean that a commercial jatropha-based energy enterprise would have to set up a separate energy generation operation from jatropha biomass in order to become energy positive and that, in effect, this would be the main business and the oil would be a by-product. The authors confirmed that the energy balance heavily depends on the details of

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[5] Yan X, Inderwildi OR, King DA, (2010) Biofuels and synthetic fuels in the US and China: A review of Well-to-Wheel energy use and greenhouse gas emissions with the impact of land-use change. Energy Environ. Sci. 3, 190–197.

[6] Fahey J, 24th Feb 2010A New Life For Jatropha. http://www.forbes.com/2010/02/23/sg-biofuels-technology-ecotech-jatropha.html

[7] Reuter's 9th April 2010 D1 Oils still in equity talks with third parties".

[8] Prueksakorn K, Gheewala SH, Malakul P, Bonnet S (2010) Energy analysis of Jatropha plantation systems for biodiesel production in Thailand. Energy for Sustainable Development 14, 1-5.

the agricultural phase as well as the infrastructure of a plantation since agricultural inputs (irrigation, fertilisers) and transportation are major energy consumers in biofuel production.

Meanwhile from China, a new paper by Guang *et al.* (2010)[9] looks in some detail about just how they could meet the national biofuel demands set out by the government. Concerned with national food security, since 2007 China has shifted its biofuel development priority from grain-based to non-grain-based biofuels. This has included jatropha as a biodiesel feedstock, but there is a growing debate there on the availability of land to grow it. The major production region for jatropha plantations lie in the Southwest of China. The authors used the agro ecological zone method (together with a consideration of social-economic constraints), in order to evaluate potential suitable land for jatropha production. This method is based on remote sensing data on land use, as well as meteorological, soil and land slope data. Their results show that while there are some potential lands to expand jatropha, the area available will fail to meet the government's targets and they tentatively suggest that China needs to reconsider its long-term targets on the development of the crop. For instance, targets are for 1.7 million ha in the next 10 to 15 years, but they estimate that there are only 70,000 ha of truly suitable lands with another 1.4 million ha of 'moderately suitable' lands.

There have also been an increasing number of news reports, adding the journalistic angle to concerns over the environmental impact of biofuels. Ben Webster in March from The Times (London)[10] reported on an new (although unpublished) government study, he has seen, which demonstrates the UK targets for the supplementing of transport fuel with biofuels, may lead to millions of hectares of forest being burnt down and turned into plantations. The study also apparently showed that using palm oil instead of fossil fuels increases emissions by 31%, hence falling far short of the EC standard of reducing emissions by 35%. However, without seeing the report it is difficult to substantiate these figures. It needs to be remembered that the majority of palm oil comes from existing plantations and not through the destruction of rainforest. It may also be that these figures are only based on the worst case scenario; where oil palm has replaced rainforest growing on peatland. The Roundtable on Sustainable Palm Oil (RSPO) are working with the palm oil industry and other stake holders including environmental groups, to make oil palm growing more sustainable[11]. As a biofuel, palm oil is considered to be the most efficient feedstock for biodiesel production. One of the aims of the RSPO is to reduce deforestation, by setting criteria for the establishment of plantations. Yet, according to The Times, the European Commission's agriculture directorate expressed concern in an internal memo that any changes to sustainability standards would damage Europe's lucrative biofuel industry. A senior official at the EC is said to have added to the memo that in his opinion: 'An unguided use of iLUC would kill biofuels in the EU.'

Currently, the EU Renewable Transport Fuels Obligation requires 3.25% of all fuel sold to come from crops - a figure expected to rise to 13% by 2020. A separate leaked document from the EC[12] that was reported in The Guardian newspaper[13] discusses a new set of rules which would

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[9] Guang WW, JiKun H, Zheng DX, 2010. Potential land for plantation of *Jatropha curcas* as feedstocks for biodiesel in China. Science in China Series D: Earth Sciences 53, 120-127.

[10] http://www.timesonline.co.uk/tol/news/environment/article7044708.ece

[11] http://www.rspo.org/

[12] Communication from the Commission to the Council and the European Parliament on the Practical Implementation of the EU Biofuels and Bioliquids Sustainability Scheme and on Counting Rules for Biofuels; draft document, BI (10) 381, undated.

[13] A surreal argument for biofuels (David Cronin guardian.co.uk, Thursday 18 February 2010)

declare palm oil sustainable if it comes from 'a continuously forested area'. The rules explain that such an area should contain trees which can reach heights of 5 metres, making up a crown canopy of more than 30 per cent. The draft of the new rules concludes: 'This means, for example, that a change from forest to oil palm plantation would not *per se* constitute a breach of the criterion.' Such apparent disregard for the spirit of the EU rules, is worrying for those who wish to see sustainable, environmentally friendly biofuel development. It supports the arguments set out by organisations such as the Roundtable on Sustainable (RSB) Biofuels in Version One of its recently published international Standards, for better biofuel production and processing[14]. The RSB Standards will be implemented through a certification system, which is currently being tested globally, and will become fully operational later in 2010. Adoption of this system by the biofuels industry needs to be encouraged if it is to legitimately take its place in the renewable fuels arena.

According to a recent EurActiv news item,[15] a review by BeCitizen, a French environmental consultancy, called for more in-depth studies in order to develop a robust methodology for calculating iLUC caused by EU biofuel production. The study analysed existing methodologies to calculate the ilUC impact on GHG emissions and highlighted major discrepancies when they are applied to different biofuel production processes. They found that percentages of a biofuel's negative or positive impact on GHG emissions vary widely depending on the crop and location of production, and assert that existing studies are not robust. The report stressed that it would therefore be "risky" to use current methods as a basis for policymaking.

Something else to worry about (Twomey *et al.*, 2010)[16] is the unintended energy impacts of increased nitrate contamination from biofuels production. They calculate that massive increases in biofuel production that are projected from the Energy Independence and Security Act of 2007 are likely to increase nitrogen contamination of water for human consumption that could increase energy used to remove nitrates by more than 20-fold – a significant increase that needs to be factored into the net energy returns, which already look marginal for much of biofuel production in the USA.

Whilst on the topic of nitrogen, we recommend some scrutiny of the paper by Bouwman *et al* (2010)[17] on the consequences of the cultivation of energy crops for the global nitrogen cycle. Using the OECD model in which a carbon tax is introduced to stimulate biofuel production, they assess the global consequences on the nitrogen cycle of implementing first- and second-generation bioenergy in the coming five decades, focusing on the nitrogen cycle. In this scenario, the area of energy crops would increase from 8 Mha in the year 2000 to 270 Mha (14% of total cropland) and produce 5.6 Pg dry matter[18] per year (12% of energy use) by 2050. This production would require an additional annual 19 Tg of N fertilizer[19] in 2050 causing global emissions of 0.7 Tg of N_2O, 0.2 Tg NO and 2.2 Tg of NH_3. In addition 2.6 Tg of NO_3 would leach from fields under energy crops. They believe that these estimates are conservative. The effects

[14] Roundtable on Sustainable Biofuels (20 November 2009). Version One: Principles & Criteria, Indicators, Definitions. (http://cgse.epfl.ch/page84341.html)

[15] http://www.euractiv.com/en/climate-environment/eu-biofuel-sustainability-criteria-inconsistent/article-188224

[16] Twomey, K. M.; Stillwell, A. S.; Webber, M. E. The unintended energy impacts of increased nitrate contamination from biofuels production. Journal of Environmental Monitoring 2010 Vol. 12 No. 1 pp. 218-224.

[17] Bouwman, A. F.; Grinsven, J. J. M. van; Eickhout, B. Consequences of the cultivation of energy crops for the global nitrogen cycle. Ecological Applications 2010 Vol. 20 No. 1 pp. 101-109.

[18] Pg = petagrams, 10^{15} grams, or one gigatonne.

[19] Tg = teragrams, 10^{12} grams, or one megatonne.

of the N_2O releases would be to reduce the GHG offset potential of biofuels by 15% in 2050. Like Twomey *et al* above, they are also concerned about the effects on nitrogen leaching, including the effects on human and ecosystem health.

Second and third generation biofuels: There is now a quite widely held opinion that first generation biofuels are more or less just a stop-gap option until the so-called second and third generation biofuels come on stream. Micro algae especially have been the subject of much recent hope but a new review (van Beilen 2010)[20] seriously questions the enthusiasm. Again, much of the problem seems to be the substantial over-estimate of yields and the difficulties of extrapolating from small-scale studies to fully scaled up operations. At full sunlight intensity for instance, productivity is only about 20–25% that which would be expected from low-light measurements, and whereas biomass yields in experimental raceway ponds reach 30–60 tonnes/ha/year, typical biomass yields of commercial systems are in the range of 10–30 tonnes/ha/year, similar to conventional tropical agriculture systems. Van Beilen summarizes the current situation: 1) the productivities achieved in large-scale commercial microalgae production systems, operated year-round, do not surpass those of irrigated tropical crops; 2) cultivating, harvesting and processing microalgae solely for the production of biofuels is simply too expensive using current or prospective technology; and 3) currently available (limited) data suggest that the energy balance of algal biofuels is very poor. He concludes that microalgal biofuels are unlikely to save the internal combustion machine.

On the other hand, Ross *et al.* (2010)[21], responding to a Nature news item[22] on the 'hype' surrounding algal biofuels, maintain that their calculations demonstrate that practical yield maxima of ~60 to 100,00 litres of oil/ha/year (assuming a maximum photosynthetic conversion efficiency of 10%) may be possible. Their economic analysis suggest that the ~400% increase in investment in microalgal biofuels observed during 2007–2008 has been sensible, given the potential to meet an internal rate of return of 15% and the future potential to achieve higher returns as biotech and process improvements are made. They tackle the question of why economically viable microalgal biofuel production systems have not yet been demonstrated: in their view, this can be explained by a) existing pilot and demonstration plants (at <5 ha) are well below the size threshold for economic viability; b) insufficient time has passed for the industry to evolve from recent capital injection (2006–2007) through to large-scale commercial production. Hence they suggest that the most appropriate and cost-effective mix of technologies are yet to be successfully integrated and optimized, and that realistic, viable enterprises are still in the commercial development phase. Time will surely tell. Indeed, genetic modification of the algae may lead to significant yield improvements[23]; and others are investigating hydrogen production from algae[24].

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[20] Beilen, J. B. Van, (2010) Why microalgal biofuels won't save the internal combustion machine. Biofuels, Bioproducts & Biorefining 4, 41-52.

[21] Ross E, King Z, Mussgnug JH, Kruse O, Posten C, Borowitzka MA, Hankamer B, (2010). An economic and technical evaluation of microalgal biofuels. Nat. Biotechnol. 28, 126-128.

[22] Waltz E, (2009). Biotech's green gold. Nat. Biotechnol. 27, 15–18.

[23] Venere, E (13th April 2010) Work aims to re-engineer algae for biodiesel production http://www.purdue.edu/newsroom/research/2010/100413MorganAlgae.html

[24] Solarvest BioEnergy Achieves Sustained Hydrogen Production in Lab, Commences Program to Scale Up Production to a Pilot Reactor, April 2010. http://findarticles.com/p/articles/mi_pwwi/is_201004/ai_n53136148/

Another paper by Clarens *et al.* (2010)[25] compares algal cultivation with switchgrass, canola and maize from a lifecycle perspective. Their results suggest that algae perform surprisingly poorly compared to the 'conventional' crops which had lower environmental impacts in energy use, greenhouse gas emissions, and water regardless of cultivation location. Only in total land use and eutrophication potential did algae perform favourably. The large environmental footprint of algal cultivation is driven predominantly by upstream impacts, such as the demand for CO2 and fertilizer. To reduce these impacts, the authors modelled the use of flue gas and wastewater to offset these environmental burdens and found that their inclusion provided a significant reduction in the burdens of algae cultivation, and the use of source-separated urine was found to make algae more environmentally beneficial than the terrestrial crops. However, these are quite severe restrictions, since as the authors point out, it will be complex to deliver waste streams to production facilities and clearly this will severely limit the scale of production that has been hoped for algae.

At present therefore, algal processing plants could both clean up wastewater and provide energy for industry, a conclusion that Chinnasamy *et al.* (2010)[26] have come to in a proof of concept study for the carpet manufacture industry. They found that a 'consortium' of 15 native algae, produced maximum biomass and lipids, removed >96% nutrients in 72 h in the wastewater from carpet manufacture. Biomass production potential was 9.2–17.8 tons/ha/year, quite similar to the range suggested by van Beilen above, whereas lipid production was only 6.8% of which 64% could be converted into biodiesel. The authors stress that further studies on anaerobic digestion and thermochemical liquefaction are required to make this approach economically viable for producing algae biofuels.

On a somewhat more encouraging note for biomass production, modelling by Davis et al (2010)[27] revealed a previously unsuspected additional nitrogen source necessary to balance biomass production estimates using *Miscanthus giganteus* as feedstock. The authors therefore suspected that nitrogen fixation was taking place and confirmed it by testing for nitrogenase activity of whole rhizomes and bacteria isolated from the rhizosphere and miscanthus tissue. Clearly a nitrogen-fixing biomass feedstock could at least partially reduce some of the expected problems of fertilizer contamination mentioned above, and this finding is likely to stimulate much new research to discover more potential nitrogen-fixing feedstocks.

By now a huge range of organisms are being studied as potential biofuel agents, either as candidate primary producers or to break down the substrate into a more easily processed form. Many of the former are summarized in a paper by Razon (2009).[28] And a new paper by Scharf

[25] Clarens, A. F.; Resurreccion, E. P.; White, M. A.; Colosi, L. M. (2010). Environmental life cycle comparison of algae to other bioenergy feedstocks. Environmental Science & Technology, 44, 1813-1819.

[26] Chinnasamy S, Bhatnagar A, Hunt R W, Das KC, (2010). Microalgae cultivation in a wastewater dominated by carpet mill effluents for biofuel applications. Bioresource Technology. 101, 3097-3105.

[27] Davis SC, Parton WJ, Dohleman FG, Smith CM, Grosso S del, Kent AD, DeLucia EH, (2010). Comparative biogeochemical cycles of bioenergy crops reveal nitrogen-fixation and low greenhouse gas emissions in a Miscanthus × giganteus agro-ecosystem. Ecosystems, 13, 144-156.

[28] 8 Razon LF, (2009) Alternative crops for biodiesel feedstock. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 4, No. 056.

and Boucias (2010)[29] provides a useful review of the potential of termite gut enzymes to break down the difficult lignocellulose molecules that are such a major component of biomass. Over more than a hundred million years, termites have evolved efficient ways of doing this using a remarkably diverse microbial consortium, including such gut micro-organisms as protozoa, bacteria, spirochetes, fungi and yeasts.

Termites have in fact been taxonomically classified into the higher and lower categories based mostly on their symbiont composition. Lower termites are hosts to both cellulolytic protozoa and a variety of non-cellulolytic bacteria, whereas higher termites lack protozoa but are hosts to a very diverse pool of cellulolytic and non-cellulolytic prokaryotes. Termites also use their own enzymes to digest lignocellulose.

The authors point out that critical research needs in commercial biomass pre-treatment are concentrated on how to develop low-cost delignification enzymes as well as for cellulose and hemicellulose solubilisation. Pre-treatment currently represents the most expensive component of bioethanol production (~20% of total costs), so this is the area where significant opportunities for innovation exist. Biologically based strategies are needed to replace harsh chemical and energy-intensive heat treatments for delignification and hemicellulose solubilization. An area of opportunity they suggest is through prospecting upstream termite gut regions where biological pre-treatment naturally occurs – in the salivary gland, foregut and midgut. So it's an intriguing thought that biomass treatment plants could one day be based on a series of steps devised by a humble insect, albeit one that, for many ecologists, is a key-stone species that dominates many tropical ecosystems. The very success of termites over eons in harsh environments suggests that this insect is well worth studying in great detail.

And finally .... in what may be landmark decision in England, plans for a biofuel power plant have been rejected.[30] More than 1,100 letters of objection were received before a council meeting which refused a biofuel power station at Avonmouth near Bristol. The plant, capable of powering 25,000 homes and fuelled by palm oil, was attacked by critics for its likely effect on rainforest destruction. Remarkably, councillors voted 6-2 against, despite advice to the contrary from planners and legal officials reminding them that they would have to justify their reasons if the company behind the application, W4B, decides to appeal. This could become something of a test case – if the decision stands, then in the future local councillors will have every right to consider international environmental issues as well as immediate local planning questions – an interesting sign that now not only finance and commerce are globalized and recalls the rallying cry of the early environmental movement: Think Globally; Act Locally!

By Dr. Peter Baker, CABI

[29] Scharf ME, Boucias DG, 2010. Potential of termite-based biomass pre-treatment strategies for use in bioethanol production *Insect Science* 17, 1–9.

[30] http://news.bbc.co.uk/1/hi/sci/tech/8532017.stm