The end of the biofuel decade

A major agricultural phenomenon of the first decade of the 21st century has been the rise of biofuels, and as it draws to a close, it's a useful time to take stock.

A new major report on biofuels by UNEP[1] helps us do this by usefully summarizing the current global biofuels situation. Biofuels now account for 1.8% of transport fuels with ethanol production having tripled between 2000 and 2007 and biodiesel production rising eleven-fold. Mandates to blend biofuel into fossil fuels for vehicles had been enacted in 17 countries by 2006, mostly requiring blending with 10 to 15% ethanol or 2 to 5% biodiesel. In short, biofuels has become a major business with all the momentum that such a new commercial endeavour can create. Thus Brazil exported 5 bn L of ethanol in 2008 and investment in biofuels rose to US$4 bn in 2007 and has most likely risen substantially since then.

So much for recent history: when we come to the future however, projections vary wildly, from a pessimistic energy provision of 40 EJ/annum[2] to 200 to 400 EJ per annum or even higher by 2050. This compares to current fossil fuel energy use of 388 EJ/annum. The report considers that the most realistic range is 40 to 85 EJ/annum by 2050. Shorter term projections expect biomass and waste to contribute 56 EJ/annum by 2015 and 68EJ/annum by 2030. Most of this increase is expected to come in USA, EU, Brazil and China.

The report makes the important point that in making future projections there are major uncertainties regarding the demand for land for agriculture, especially considering expected low growth in crop yields, expanding populations as well as yield and land degradation due to climate change.

These uncertainties extend to Life Cycle Assessments, which, depending on the study, show wide variations in efficiencies. The highest variations are observed for biodiesel from palm oil and soya with the highest greenhouse gas saving coming from biogas derived from manure and ethanol derived from agricultural and forest residues as well as biodiesel from wood, though this latter is based only on experimental plants. And despite many studies, the UNEP report finds them lacking in assessment of indirect effects, including eutrophication, acidification, human and eco-toxicity potential or ozone depletion. Significant variation in LCAs result from nitrous oxide emissions, which are a particularly strong GHG –many of the LCA studies have used rather low values from the IPCC, but if the higher levels suggested by Crutzen *et al*.[3] are corroborated, the LCA studies will have to be recalculated . Tellingly too says UNEP, none of the LCA studies look at biodiversity effects.

Estimates of land required for biofuels vary widely, depending on basic assumptions – the feedstock, geographical location and levels of input and yield increases expected. The range of estimates is staggeringly broad, from 35 to 166 million ha by 2020, which is a conservative range, assuming no new biofuels policies are promoted. It is calculated that somewhere between 118 to 508 million ha would be required to provide 10% of global transport fuel demand.

However, by 2020 somewhere between 144 and 334 million ha of extra land is needed for food, so there is currently no convincing strategy or even concept of where biofuels will be grown.

Some indication of where things might be heading can be found in a new article by Tom Simpson[4]. He points to the many deficiencies of corn based ethanol and seriously questions its viability on environmental and economic grounds.

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[1] *Assessing Biofuels*, UNEP 2009 www.unep.fr/scp/rpanel/pdf/Assessing_Biofuels_Full_Report.pdf

[2] EJ = exajoules = 10^{18} joules

[3] Crutzen PJ, Mosier AR, Smith KA Winiwarter W, 2007. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmos. Chem. Phys. Discuss*., 7: 11191–11205

4 Simpson T, 2009 Biofuels: The Past, Present, and a New Vision for the Future. *BioScience Vol. 59 No. 11* 926-927

Simpson believes that the future for US biofuels at least is more likely in perennial biomass crops, like switchgrass or fast-growing hardwoods, which lose 75 to 90 percent less N to water, reduce greenhouse gas emissions, provide habitat, and can be used to replace crude oil without conversion to ethanol.

In another recent paper, Jerry Melillo[5], with his colleagues of the Woods Hole Marine Biological Laboratory in the US, has modeled how growth in biofuel production will change world agriculture during the 21st century. They concentrate on the most likely future— which like Simpson, they believe is cellulosic biofuels from whole plants such as fast-growing grasses, rather than today's biofuel crops mostly derived from food plants. Surprisingly perhaps, they believe that Africa is the best place to grow biofuels, and the one that will lead to most carbon capture in the long run. But their model also shows that expansion of biofuel crops is likely to cause a net global release of greenhouse gases during the first half of the century, as land is cleared and fertilized. In the right circumstances the CO_2 account, they find, could move into profit by mid-century, but the nitrous oxide account never does. The problem with this of course is that with accelerating climate change, there is an urgent need to reduce emissions over the next 20 years, so it is very questionable whether it is justifiable to allow the carbon account of biofuels to enter what looks like a prolonged period of deficit.

Corroboration for this comes from a new paper by Vuichard et al., [6] which through modeling shows a carbon deficit of at least 25 years for any implementation of a grassy biofuel production strategy on the 20 million ha of abandoned Soviet agricultural lands, compared to their current state of inactivity.

An interesting new angle on the enigma that is jatropha comes in a recent paper by Maes *et al*.[7] who set out to define the climatic conditions in its area of natural distribution by combining the locations of herbarium specimens with corresponding climatic information. Most specimens (87%) were found in tropical savannah and monsoon climates and in temperate climates without dry season and with hot summer, while very few were found in semi-arid and none in arid climates. A surprising -+-+---------------------------------95% of the specimens grew in areas with a mean annual rainfall above 944 mm per year and an average minimum temperature of the coldest month (Tmin) above 10.5°C. The mean annual temperature range was 19.3-27.2°C.

However when they compared these conditions with those in 83 jatropha plantations worldwide, they found a very different story. Roughly 40% of the plantations were situated in regions with a drier climate than in 95% of the area of the herbarium specimens, and 28% of the plantations were situated in areas with a Tmin below 10.5°C. They suggest therefore that many plantations are sub-optimally located, holding the risk of chronic low productivity or cold damage.

Another jatropha paper by Kheira and Atta[8] studied its suitability under Egypt's climate in unused lands under scarce water conditions. The results revealed that the average water consumption rate of the jatropha bush was 6 L per week throughout the growing season, which means that jatropha can survive and produce full yield with high quality seeds

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5 Melillo JM et al., 2009. Indirect Emissions from Biofuels: How Important? *Science* 326: 1397 - 1399

[6] Vuichard N, Ciais P, Wolf A, 2009. Soil Carbon Sequestration or Biofuel Production: New Land-Use Opportunities for Mitigating Climate over Abandoned Soviet Farmlands. Environ. Sci. Technol. 2009, 43, 8678–8683

[7] Maes, WH, Trabucco A, Achten WMJ, Muys B, 2009 Climatic growing conditions of Jatropha curcas L. *Biomass and Bioenergy* 2009 Vol. 33 No. 10 pp. 1481-1485

[8] Kheira, A, Atta N 2009, Response of Jatropha curcas L. to water deficits: yield, water use efficiency and oilseed characteristics. *Biomass and Bioenergy* 33: 1343-1350

under minimum water requirements compared to other crops. The yield of extracted oil however was extremely low, achieving only 58 kg oil yield per ha at an optimal 100% of potential evapotranspiration.

The sheer complexity of biofuels is brought out well by a recent exchange of letters in the December 4th edition of Science[9]: various scientists well-known in the biofuels sector comment on a previous article by Tilman *et al.*[10] that argued that the search for beneficial biofuels should focus on feedstocks that (i) do not compete with food crops, (ii) do not lead to land-clearing, and (iii) offer real greenhouse-gas reductions. The various letter writers suggested additional criteria:

iv) **Rist *et al.*: the maximization of social benefits**, for example the negative impacts of oil palm development such as poor wages and labor standards, impacts on health and local culture, "land grabbing," and the loss of environmental goods and services.

v) **Biksey & Wu: environmental and health impacts of the co-products** that arise during generation of biofuels from feedstocks. For example, maize-based ethanol production results in the production of by-products sold as animal feed. It has been found that any mycotoxins in the original maize become up to three times as concentrated in these co-products and production of biofuels from waste materials may release chemicals such as dioxins and heavy metals that could result in unintended environmental and public health exposures

vi) **Duffy *et al.*: algae were overlooked by Tilman *et al.* as a solution**. They claim that about 30 million ha of algal culture would yield more than 100% of the US petroleum diesel usage, even assuming modest algal productivity, microalgae being typically at least an order of magnitude more productive than even the fastest growing terrestrial feedstock crops. However as we reported in a previous BIE news item, not all scientists agree with this optimistic assessment of the efficiency of algae.

vii) **Kauppi & Saikku: the neglected role of forests and carbon capture and storage**. Trees offer promise as an energy crop in areas where they grow well on degraded lands. A new and permanent reservoir of carbon is created as planted forest develops toward a steady state where mature trees mix with young saplings. Forests also offer a great variety of ecosystem services such as biodiversity promotion, nutrient retention, and flood protection. Timber crops can be harvested at any time during the year, and the durable wood serves as an interim energy storage—two assets for energy transport logistics. The carbon budget of wood is competitive against other materials in end uses such as construction.

Opportunities to use side-products from wood-processing industries in electricity production should be fully explored. As Simpson above also suggests, biopower by almost any criterion deserves attention. Greenhouse gas benefits are better achieved making electricity than fuels.

viii) **Lal & Pimentel: the dangers of using crop residues and harvesting biomass from double crops and mixed cropping systems.** Retention of crop residues on soils, including the biomass produced from cover crops, is essential to numerous ecosystem services such as carbon sequestration, conservation of soil and water, and high use-efficiency of inputs for increasing and sustaining agronomic productivity. They point out that the almost perpetual food deficit in sub-Saharan Africa is attributed to severe soil degradation caused by extractive farming practices that involve continuous removal of crop residues for use as traditional biofuels and cattle feed that has created a negative nutrient budget. Soils are a source of greenhouse gases when prone to accelerated erosion and when under management that

9 Science Letters, vol 326 4th December 2009, 1345-46.

10 Tilman D Socolow R, Foley J, Hill J, Larson E, Lynd L, Pacala S, Reilly J, Searchinger T, Somerville C, Williams R, 2009. Beneficial Biofuels—The Food, Energy, and Environment Trilemma. *Science*, 325: 270 - 271

creates negative carbon and nutrient budgets. Furthermore, crop residues and other biosolids are essential to maintain activity and species diversity of soil biota (micro and macroorganisms) and to improve soil structure and tilth. Lal and Pimental urge that the indiscriminate removal of crop residues and harvesting of biomass from cropland soils is supported neither by science nor by conventional wisdom.

ix) **Spangenberg & Settele: the downside of growing perennials on degraded lands that can no longer be used for agriculture.** Land fertile enough to grow plants offering substantial yields for biofuels, should be suitable for agriculture as well. Even if not used today, this land could be kept as a productive reserve and used later to combat the foreseeable problems in feeding the world in the future. If the land is not fertile enough for that purpose, the perennial energy plants will probably be dependent on anthropogenic inputs such as fertilizers and, in some regions, irrigation. These are the factors disrupting the energy balance; nitrogen fertilization is the basis for nitrous oxide emissions with the potential to overcompensate all greenhouse gains. Economically, such plantations would not be viable without intensive farming practices, raising doubts regarding the expected benefits for biodiversity and wildlife.

Given that currently only about 10% of the global primary energy demand is covered by renewable resources and that humans already appropriate large percentages of the potentially available biomass (20 to 40% globally, 50% in some industrialized countries, up to 90% in intensively farmed regions) (*3*), Spangenberg and Settele are sceptical about the potential of biofuels and they cannot support their demand that "a robust biofuels industry should be enabled now."

The authors of this final letter end by suggesting to 'better look before we leap', which is a fitting epitaph on the 'noughties' (2000-2009) – when so many catastrophic political and economic decisions were made on flimsy evidence or a dogmatic, one-sided view of life. Let us hope that the future of biofuels can be placed on firmer ground by thoroughly modelling and researching their true potential to reveal all the complexity and long term ramifications that we are now just beginning to comprehend.