

Biofuels Are Not the Answer

The threat of global warming has led governments around the world to encourage the use of biofuel, in particular in the transport sector, in the hope of displacing fossil fuel. The UK, following an EU Biofuels Directive, is introducing a Road Transport Fuel Obligation (RTFO), requiring fuel providers to ensure that 5% of their total road transport fuel sales “is made up of fuels from renewable sources” by 2010¹.

It is already well-known, through the efforts of, in particular, George Monbiot, that a large-scale diversion of agricultural land to the production of biofuel will set up competition between food and fuel, between people and cars. Vast tracts of rainforest are already being cleared to create more land on which to grow biofuel crops, such as oil palm. Governments may argue that they can manage these problems, whilst continuing to promote biofuel use. This is doubtful.

But there are even more fundamental arguments against biofuels. This paper shows that the use of biofuel to supplement fossil fuel for vehicle transport is not only disastrous in practice, it is also flawed even on its own terms, in two distinct ways:

- Plant-growth on land is one of the main ways in which CO₂ is removed from the atmosphere. Land is therefore a resource in the fight against global-warming. Even under optimistic assumptions, growing biofuel crops will not reduce atmospheric levels of CO₂ over any timescale of up to more than a century, compared to preventing deforestation or even simply leaving already cleared land alone and allowing natural plant growth to capture carbon.
- We know that within a few decades we must dramatically reduce our reliance on fossil-fuels, especially in the transport sector, where capturing and sequestering carbon emissions would be very expensive. In terms of achieving this objective, the use of biofuel is counter-productive. Instead of encouraging investment in energy supplies that are renewable for the long-term, measures such as the RTFO incentivise businesses and individuals to make further investments in technology for burning carbon fuels. Government should instead encourage a technological path from hybrid cars, through plug-in hybrids, to electric cars. Instead of continuing to burn carbon, our future transport energy needs can be met by the generation of electricity using true renewable and/or nuclear technologies.

Biofuels are not the answer.

Biofuel crops need too much land

The main objections that have been voiced against encouraging biofuel use through policies such as the UK's RTFO concern the vast amount of land that will be required to grow the crops to produce the required biofuel. It is worth revisiting the problems that have been highlighted, although the main purpose of this paper is to show that the promotion of biofuels is flawed in principle, not just in practice. The issues that have already been raised should, in themselves, at least raise questions as to the wisdom of current government policy in this area.

The argument in support of the use of biofuel is that, since the carbon released when the biofuel is burned was absorbed when the plant was grown, it is “carbon-neutral”. This argument is entirely fallacious. It is spin to apply the terms “carbon-neutral” and “green” to biofuels.

The point is that the “carbon-neutral” argument takes no account of the land required for biofuel crops. And when you start to look at the numbers, as, for example, George Monbiot has done, it's obvious that significant areas of land are needed to displace even a small proportion of our carbon emissions. Monbiot notes that to run all the UK's “cars and buses and lorries on biodiesel... would require 25.9m hectares. There are 5.7m [hectares of arable land] in the United Kingdom.”²

Meeting the RTFO obligation to ensure that just 5% of road transport fuel sales are “made up of sales from renewable sources”³, will therefore require the equivalent of over a fifth of the UK’s available farmland. I’ve heard similar points made in a presentation by the Chief Scientist of BP.⁴ Informed sources are hardly necessary, however: a child could do the arithmetic. On a global scale, the more land is used for biofuel crops, the less is available for growing food and for natural ecosystems, which themselves store vast amounts of carbon.

The idea that large-scale biofuel production will cause a squeeze on land resources is no longer just theoretical. Food prices are already rising as a result of crops being diverted into biofuel production⁵ and many species, including orangutans, are threatened with extinction by the scale of land clearance for palm oil plantations in Borneo⁶.

But the direct effects on the use of land are not even the main reason why large-scale biofuel use is a disastrous policy. Their land-use requirement makes them counter-productive in the fight against global warming, in principle.

Why biofuel use doesn’t reduce atmospheric greenhouse gas levels

Of the biofuel crops currently grown in Europe and North America, oilseed rape is the most productive, yielding up to nearly 1.5 tonnes of fuel per hectare.⁷ Let’s make the very generous assumption, for the sake of argument, that the use of a tonne of such fuel prevents the emission of a tonne of carbon into the atmosphere from fossil fuels that would otherwise have been consumed.

Unfortunately, the best case biofuel yield of 1.5 tonnes of fuel per hectare is before taking account of the energy required for its production. We must subtract, from our gross yield of 1.5 tonnes of fuel per hectare, the energy required for the production of fertilizers, pesticides and herbicides; processing; and transport to and from the processing plant. When I first became concerned about the scale and unsustainability of the biofuel industry, I assumed that these energy costs must be trivial for anyone to even contemplate growing crops in order to produce fuel. But it turns out that in fact these energy costs are huge. There’s even a very real scientific debate about whether there is any net energy saving from some current (and some proposed) biofuel crops at all.⁸ That’s right: an unintended consequence of biofuel quotas, tax incentives, direct agricultural subsidies⁹ and tax-breaks, such as for fuel for farm vehicles¹⁰, may be that people end up running their cars on fuel containing less energy than was used in its production!

The UK Department for Transport considers that “the overall lifecycle carbon balance of conventional biofuels (taking into account fertilizer use to grow the crops etc.) typically lead to greenhouse gas emissions of around 50% less compared with fossil fuels.”¹¹ The best case of displacing 1.5 tonnes of fossil fuel carbon emissions per hectare of biofuel crop is therefore reduced to just 0.75 tonnes per hectare.

Forested land stores at least 100 tonnes more carbon per hectare than does cropland.¹² In Europe, the land currently being used to grow biofuel crops would revert to forest if left alone (tree-planting would accelerate this process, of course). What’s more, the growing trees would take up carbon from the atmosphere faster than the biofuel crop could save carbon emissions by displacing fossil fuels.¹³ Biofuel crops would have to be grown for at least 130 years (100 tonnes divided by 0.75 tonnes per year) to justify cultivating the land rather than growing a forest.

If a forest is felled to obtain land to grow biofuel crops the situation is even worse. The deforestation causes 100 tonnes of carbon to enter the atmosphere immediately and the biofuel “savings” happen gradually over time. We have to apply the same logic as is used in assessing carbon-offset tree-planting schemes.¹⁴ Only after double the figure of 130 years does the number of “tonne years” of reduction in atmospheric CO₂ due to the accumulated biofuel emissions “saving”

of 0.75 tonnes of carbon per year compensate for the 100 tonnes emitted when the forest was destroyed. The “pay-back” period for felling a forest to produce land on which to grow biofuel crops is in fact an astonishing 260 years!

Moreover, mature forests worldwide have been consistently shown to be taking up a tonne or more of carbon per hectare, year on year. It is believed that this is due to the “carbon dioxide fertilisation effect” whereby plant growth is stimulated by elevated levels of carbon dioxide in the atmosphere.¹⁵ That is, the world’s forests are acting to reduce the impact of our carbon emissions. This service, alone, is more effective in removing carbon dioxide from the atmosphere than growing biofuel crops on the same land. This is before we take any account of the carbon released by destroying the forest. There must be a limit to how long the carbon dioxide fertilisation effect can continue – though we don’t know what this is – but, until it weakens significantly, growing biofuel crops can never achieve a carbon saving compared to a forest on the same land.

At least in Europe, it’s difficult to believe that trees will not grow on land that is currently being used to grow biofuel crops, since the whole continent was covered in forest a few thousand years ago. Even in areas where abandoned farmland reverts to grassland or scrub, it would eventually store around 70 tonnes more carbon per hectare than as cropland.¹⁶

In the tropics, about 3 tonnes of palm oil is being produced on average per hectare of plantations in, for example, Indonesia.¹⁷ The “pay-back” time for palm oil is therefore of a similar order to that for biofuel crops grown at temperate latitudes, given the carbon content of tropical forests.¹⁸ In practice, though, this time is much greater, as peat bogs are reportedly often drained to clear the land.¹⁹ The problem is compounded further if we accept reports that, in some cases, the land is so depleted after just 25 years that very little will subsequently grow on it!²⁰

It takes far too long for the cultivation of biofuel crops to lead to net carbon savings, compared to reforesting the same land even whilst continuing to use fossil fuels. Growing biofuels makes it more, not less, difficult for us to solve the global warming problem, unless we assume we can afford to defer carbon emission reductions for more than another 130 years. To avert dangerous climate change, we must act over the next few decades, and many nations have already agreed to do so by signing the Kyoto Protocol.

Biofuel, energy, land-use and forests – a global perspective

Historically, our demand for energy has continually increased, except when checked by a disruption to supplies. Vehicle engine efficiency has only improved when oil supply has been constrained, for example by OPEC in the 1970s.

The use of biofuel acts to increase the overall supply of fuel. The price at the pumps will therefore fall²¹ and total fuel use will increase: on average, people will drive more. The basic premise that biofuel reduces carbon emissions by “displacing” an equivalent amount of fossil fuel is false. At best, only a proportion of fossil fuel will be displaced.

Our use of land has continually increased throughout history, except during periods of high mortality, such as the Black Death in the 14th century.²² Unchecked, human societies eventually exploit all available land. The promotion of biofuels accelerates this process.

The problem is compounded by global markets. Promoting biofuel crops in Europe and North America inevitably increases agricultural production in those areas of the world where there are fewest restrictions on clearing natural forest. At present, the total area of the world’s forests is shrinking, due to a lack of constraints on their economic exploitation. We must therefore assume that allocating land to biofuel crops causes the destruction of an equivalent area of natural forest

somewhere in the world. We have to use the figure of 260 years for the carbon pay-back period for biofuel production, and not the figure of 130 years.

Governments in the developed world argue that they can prevent biofuel demand causing deforestation overseas by ensuring that production is “sustainable”. This is not possible, for two reasons:

- The UK government, or even the EU or the US government, is unable to enforce such trade rules: at best they may displace some of the most destructively-produced biofuel to other markets;
- Even if, for example, international action succeeds in confining biofuel production to land already cleared of forest, a step suggested by Friends of the Earth and WWF²³, then food producers or subsistence farmers will end up clearing virgin forest, as is reported to be happening in Brazil.²⁴ Morally, it’s much more difficult to take action against encroachment by subsistence farmers onto forested land, than to solve the problem at its root cause by not growing biofuel crops.

Many experts, such as Lord Stern, have stressed the importance of preventing deforestation and encouraging the recovery of natural forest ecosystems over the coming decades.²⁵ Whilst only part of the overall solution to the problem of dangerous climate change, maintaining and expanding forest stores of carbon is capable of reducing net annual global carbon emissions to the atmosphere by almost 30%.²⁶

Non-agricultural biofuels

The argument is often used that tax and other incentives put in place now will “seed the market” for non-agricultural or “second-generation” biofuels, such as bio-ethanol produced from wood-chips or grasses, by encouraging the development and adoption of vehicle engines able to run on bio-ethanol or bio-diesel and the construction of distribution infrastructure for biofuels. Second-generation biofuels, it is argued, will have fewer of the drawbacks of current, crop-based biofuels. In particular, they will not need to be grown on land suitable for food crops.

Let’s suppose, for the sake of argument, that current biofuel crops are “bad” and second-generation biofuels will be “good”. Is it necessary to roll out technology now, so that users can switch to second-generation biofuels in (say) 5 years? Clearly not. Consumers are able to switch to vehicles able to use biofuel very rapidly, since vehicles with suitable engines are already available at a relatively small price premium (£600 in the case of Saab²⁷).

But will second-generation biofuels avoid the problems intrinsic to the use of crop-based biofuels? This cannot yet be determined as such technologies are not yet ready for deployment. Second-generation biofuels may struggle to achieve a net energy-gain, just like present biofuels. Government must evaluate any future biofuel technologies, before, not after, providing incentives for their deployment.

As well as the net energy yield, the overall carbon balance of future biofuel technologies must be taken into account. Two perspectives are worth considering:

- Many second-generation biofuel technologies rely on developing ways of converting woody materials into liquid fuel. Sweden, for example, hopes to produce ethanol from wood-chips.²⁸ The raw materials for such processes do not decay rapidly in nature, so using such technologies causes carbon to be released into the atmosphere far earlier – perhaps decades earlier – than would otherwise have been the case. This increases the amount of CO₂ in the atmosphere at any given time, and must be taken into account in evaluating any particular biofuel technology.

- Using land to produce biofuel of any kind reduces the amount of carbon it stores. The argument is no different in principle for biofuel production from “sustainable” forests than for crop-based biofuel production. Removing wood regularly from any forest will reduce the amount of carbon it holds. This must be taken into account in evaluating any land-use change. Natural forest will achieve a much higher peak level of carbon per hectare at maturity, with some carbon in the form of slowly decaying wood, than will a forest used as a resource. This argument does not apply just to forests. Production of biofuel from grassland species, such as switchgrass, will inevitably affect the overall carbon balance in the area in which they are harvested, most significantly by affecting the soils.²⁹

With all biofuels, the impact on water resources must also be factored into the equation. Some very thirsty biofuel crops have been proposed, such as willow.

Biofuel can't compete with solar power

The least environmentally destructive biofuel technology we can hope for is to produce fuel from algae grown in tanks in the desert, which would be many times more efficient than any other biofuel technology. But fundamental limitations remain. Biofuel crops of any kind are a very inefficient way of capturing energy from sunlight. Let's compare biofuel crops with solar power generation, not because that's the only alternative technology, but because it's an alternative use for the available land. Current photovoltaics are 10-20% efficient. Photosynthesis is, at best, able to convert sunlight into energy with an efficiency of a few percent.³⁰ And that's before all the extra energy costs of fertilizers, water, processing, and transport to and from the processing plant are added in. It doesn't matter where in the world you are, you'll always be able to obtain more energy in the form of electricity from sunlight than in the form of biofuel from plants. If we can't produce enough electricity from sunlight in the UK for our energy needs, then we certainly can't grow enough biofuel crops.

Comparing the potential of biofuel with that of solar power suggests that, however sophisticated it becomes, biofuel technology is not the best way to meet our energy requirements in the future, let alone the best way to minimise atmospheric CO₂ levels while generating energy. The second major problem with encouraging the use of biofuels is that it leaves us on a dead-end technological path.

Promoting the development of true renewable technologies

Arguably, government shouldn't back a specific technology, since the data required to make such a decision are always imperfect. Ideally, government activity should be limited to creating a level playing-field and making sure industries pick up their environmental costs, for example, by using taxes, such as a Fuel Duty Escalator, to represent externalities. The political reality, though, is that government cannot, in practice, just apply the simplest policy and (gradually) tax fossil-fuel vehicles off the road. This would force consumers to find other transport options, thereby letting the market pick the “winning” technologies. Unfortunately, the public demands that government softens the blow by providing alternatives. In supporting the use of biofuel, though, governments are backing the wrong technology.

It is already clear that a migration path exists from petrol- or diesel-driven vehicles to the use of hybrid engines, and then, via plug-in hybrids, to electric cars.³¹ Of course, this is just the path the mainstream user is likely to follow: electric cars already meet the needs of many drivers. The problem is not so much how to stimulate further technological advances as how to change people's habits. Providing stronger incentives for a painless transition to hybrid vehicles is a vital first step in this process.

Not only do incentives to use biofuels encourage their use today, they also promote further

investment in technologies that support the use of carbon-based fuels. The effect is analogous to building a coal plant. Cars bought and new fuel infrastructure built now will remain in use for many years. In a presentation I attended recently³², BP's Chief Scientist was very clear how biofuels fit into the company's existing supply-chain, with relatively little disruption. In effect, biofuels are a form of support for the oil industry!

We know that prices of true renewable power and electric or hybrid vehicle technologies will continually come down, and their performance improve, because this is what has happened with every technology in the past, from aeroplanes to radios and PCs, from cars to flat-screen TVs and digital cameras. A general rule can be formulated that the cost of products based on technology decreases as their use increases over time, primarily due to economies of scale and learning effects. The reverse is true, though, with products based on the use of resources. The cost of limited resources tends to increase, at least relatively, over time, as the cheaper sources of supply become exhausted.

Plug-in hybrid vehicles and electric cars are complementary to many forms of renewable energy technology, for the simple reason that they store electricity until it is needed. Charging can therefore take place when there's spare electricity. Wind energy (intermittent), nuclear (always on) and solar (depends on the time of day and the weather) don't always produce power when it's wanted. Also, the ability to charge plug-in hybrids or electric cars overnight minimises the need to upgrade grid transmission capacity, which depends on the peak load, not the total power delivered.

How can government encourage the transition to vehicles running entirely on renewable electricity?

First, government must invest in infrastructure, specifically the national electricity grid, and in particular in undersea cabling to encourage investment in off-shore wind-power projects; and in measures to encourage the development of markets for renewable electricity, such as international electricity grid interconnections and real-time variable rate electricity pricing together with "smart-metering"³³ for consumers. This would be a much better use of the funds that are currently being spent on tax-breaks for biofuels and schemes such as the RTFO, and the principle is hardly new – UK consumers already buy off-peak nuclear-generated electricity from France.

Second, simply providing further incentives for the uptake of vehicles using hybrid engines – which are “no regrets” in that they allow the recovery of energy that would otherwise be lost in braking – may result in a greater reduction in carbon emissions per pound spent than is expected from measures to encourage the use of biofuel, let alone than is actually the case in practice.

The EU asserts that: "Biofuels are an expensive way of reducing greenhouse gas emissions."³⁴ But they do not even do that. A far better use of the subsidies for biofuels would be to spend the money on accelerating the development and adoption of true renewable technologies.

- ¹ “Consultation on the draft Renewable Transport Fuel Obligations Order”, accessed online, on 30/3/07, at <http://www.dft.gov.uk/consultations/open/drafttrfo/>.
- ² “Feeding Cars Not People”, George Monbiot, The Guardian, 22/11/04, accessed online, on 30/3/07, at <http://www.monbiot.com/archives/2004/11/23/feeding-cars-not-people/>.
- ³ Consultation on the Draft Renewable Transport Fuel Obligations Order, Department for Transport,
- ⁴ “The Promise of Energy Biosciences”, 7/2/07, Steven E. Koomin, Chief Scientist, BP plc, 5th Annual Lecture Series in Sustainable Development 2007, Centre for Sustainable Development, Cambridge University Department of Engineering.
- ⁵ As reported for example in the Guardian on 2nd February 2007: “Tortilla rising: Protest over price of corn”.
- ⁶ See, for example, “Palm oil: the biofuel of the future driving an ecological disaster now”, the Guardian, 4/4/07, p.23. The Biofuelwatch website, <http://www.biofuelwatch.org.uk/index.php>, documents numerous other examples of the destruction of irreplaceable old growth forests and other habitats for biofuel production, destruction often accompanied by the release into the atmosphere of vast amounts of carbon.
- ⁷ “Feeding Cars Not People”, George Monbiot, the Guardian, 22/11/04, accessed online, on 30.3.07, at <http://www.monbiot.com/archives/2004/11/23/feeding-cars-not-people/>. Wikipedia quote 1 tonne/hectare/year, at http://en.wikipedia.org/wiki/Energy_crop, accessed 1/4/07.
- ⁸ The prime example of a biofuel crop with a marginal net energy saving is corn grown in the US. See, for example, “The False Hope of Biofuels”, Washington Post, 2/7/06, accessed online on 4/4/07, at <http://www.washingtonpost.com/wp-dyn/content/article/2006/06/30/AR2006063001480.html>. “Is Ethanol for the Long Haul”, by Matthew L. Wald, Scientific American, Jan 2007, p.28-35, also includes a discussion of the net energy gain of producing ethanol from corn. Wald concludes that: “...the consensus among the analysts is that even if the net energy value of ethanol [from corn] is positive, the margin is small.” (p.33).
- ⁹ The EU’s Common Agricultural Policy currently pays farmers €45 per hectare of energy crops. This can only be claimed for 2 million hectares – <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1844&format=HTML&aged=1&language=EN&guiLanguage=en>, accessed 5/4/07.
- ¹⁰ For example, “red diesel” in the UK is taxed at a much lower rate than fuels for general use. See, for example, <http://www.fwi.co.uk/Articles/2005/08/12/88510/dissecting-red-diesel-rules.html>, accessed online on 5/4/07. This matters because the end product, biodiesel or bio-ethanol also attracts less duty than the fuels with which it competes: see, e.g. http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageLibrary_ShowContent&id=HMCE_PROD1_024855&propertyType=document#P296_3751 (accessed 5/4/07).
- ¹¹ Letter from Aaron Berry, Policy Adviser, Department for Transport, to the author, 2/12/05.
- ¹² IPCC, Third Assessment Report (“the TAR”), Scientific Basis, section 3.2.2. This is a very conservative figure, as it is based on the average for the carbon stored in forested regions of the globe, which must include a large amount of land unsuitable for agriculture. Some studies suggest far more than 100 tonnes more carbon is contained in each hectare of mature forest than in a hectare of cropland: “The Economics of Climate Change: The Stern Review”, Cambridge University Press, 2007 (“the Stern Report”), section 25.2, “Understanding deforestation”, p.610, quotes “up to 1000t CO₂ per hectare, which is equivalent to about 275 tonnes carbon/hectare.
- ¹³ One study showed that young tree stands on grassland take up more than 1.5 tonnes of carbon per hectare each year, for more than half a century, after the first 5 years, and more than 2.5 tonnes per hectare each year, for 40 years, after the first 15 years, “Accounting for Forest Carbon”, Technical Document 11, The Edinburgh Centre for Carbon Management, accessed online on 4/4/07, at <http://www.eccm.uk.com/publications.html>.
- ¹⁴ “Accounting for Forest Carbon”, Technical Document 11, The Edinburgh Centre for Carbon Management, accessed online on 4/4/07, at <http://www.eccm.uk.com/publications.html>.
- ¹⁵ The TAR, Scientific Basis, notes in section 3.2.2, that: “...in the absence of disturbances that remove carbon from the ecosystems (such as harvest or fire)... [a]nnual NEP [net ecosystem production] flux measurements are in the range 0.7 to 5.9 MgC [i.e. tonnes of carbon] for tropical forests and 0.8 to 7.0 MgC/ha/yr for temperate forests...”. A paper, “The Magnitude and Permanence of Forest Carbon Sinks”, by the Edinburgh Centre for Carbon Management, accessed online on 4/4/07, at <http://www.eccm.uk.com/publications.html>, discusses why studies of over 70 forests “have demonstrated that these forests are sequestering up to six tonnes of carbon per hectare per year.” They suggest, plausibly, that part of the explanation is the “carbon dioxide fertilization effect”, whereby much of our carbon dioxide emissions are offset by increased plant growth, which removes carbon from the atmosphere. Obviously, the less forest there is, the weaker this effect will be in the future.
- ¹⁶ TAR, Scientific Basis, section 3.2.2, averaging the figures from two different sources quoted for “temperate grassland and shrubland”. Cultivation gradually removes carbon from soil, as organic material is taken away, reducing the amount of detritus reaching the soil, whereas decay processes continue at the same rate. Decay processes on cropland are also accelerated by ploughing, which exposes buried detritus to the atmosphere. The ecologist David Tilman of the University of Minnesota claims that “mixed prairie grasses [grown on abandoned farmland and used to produce biofuel and for biomass energy] won’t increase greenhouse gas emissions – mostly carbon dioxide – at all, and may even be ‘carbon negative’ because they will store carbon. This storage could go on for as long as 100 years. Removal could range from 1.2 to 1.8 U.S. tons of carbon dioxide per acre [about 0.85 to 1.3 tonnes of carbon per hectare] per year.” http://www1.umn.edu/umnnews/Feature_Stories/Back_to_the_future_prairie_grasses.html, accessed 11/4/07. Tilman is

saying that the native grasses are restoring the carbon lost from the soils over decades of cultivation, though his claim that this will continue through a century of repeated harvesting may be a little optimistic.

¹⁷ Wikipedia, accessed 19/4/07. http://news.mongabay.com/2006/0425-oil_palm.html, accessed 19/4/07, notes that “in Indonesia,... oil-palm plantations covered 5.3 million hectares of the country in 2004, according to a report by Friends of the Earth-Netherlands. These plantations generated 11.4 million metric tons of crude palm oil...”. This implies a yield of 2.15 tonnes/hectare/year (11.4 million tonnes a year/5.3 million hectares). Figures attributed to “Oil World” shown graphically in a presentation by Gail Smith, Unilever Sustainable Agriculture, at the Cambridge Energy Forum, Feb 2007, accessed online at <http://www.cambridgeenergy.com/event-2007-02-08.htm>, on 19/4/07, show similar production, but for about half the area (on a graph). The Oil World graph for the cultivated area is certainly misleading since the UN’s Food and Agricultural Organisation (the FAO, statistics online at <http://faostat.fao.org/>) gives 3.32 million hectares as the “area harvested” in 2004, but does not say how much more land was planted, but not harvestable. Historical figures published by the Foreign Agricultural Service of the US Department of Agriculture (available online at www.fas.usda.gov/gainfiles/200312/146085249.pdf) suggest the harvested area is about 80% of the total planted area. This implies a planted area of 4 million hectares and a yield of 2.85 tonnes/hectare/year (11.4 million tonnes a year/4 million hectares). A palm oil yield of “up to” 5 tonnes/hectare is often quoted. Achieving 5 tonnes/hectare requires ideal weather conditions and is not consistently achievable.

¹⁸ 157 tonnes/hectare, above ground, TAR, Scientific Basis, section 3.2.2, averaging the figures from two different sources quoted for “tropical forests”. A “pay-back” period in excess of 100 years (157 tonnes per hectare divided by 3 tonnes yield per hectare per year, doubled to take into account that forests are being cleared to grow oil palms, rather than just not being allowed to return) is therefore implied in the carbon budget for oil palm plantations in Indonesia, before allowing for the energy costs of inputs, processing and transport; before allowing for the loss of soil carbon (the TAR suggests that tropical forest soils contain about 120 tonnes of carbon per hectare); before allowing for declining yields; and before allowing for the carbon dioxide fertilization effect.

¹⁹ <http://www.monbiot.com/archives/2005/12/06/worse-than-fossil-fuel/>, accessed 30/3/07.

²⁰ http://news.mongabay.com/2006/0425-oil_palm.html, accessed 30/3/07.

²¹ All else being equal. To be effective in displacing fossil fuel use, policies like the RTFO must be complemented by increases in fuel duty to prevent any increase in the overall demand for fuel. Taking a global perspective, biofuels will only displace fossil fuels if an amount of fossil fuel equivalent to the biofuel used remains in the ground. Mechanisms to ensure this happens are not in place.

²² For an interesting discussion of the possible climate consequences of pandemics, see “How Did Humans First Alter Global Climate?”, by William F. Ruddiman, *Scientific American*, March 2005, p.46-53.

²³ See, for example, the “RSPB, WWF, Greenpeace, Oxfam and Friends of the Earth joint statement on biofuels”, dated 20/3/07 and available online, at http://www.wwf.org.uk/news/n_0000003698.asp (accessed 27/4/07).

²⁴ “Rainforests pay the price of ethanol”, the *Independent*, 6/4/07, letter to the Editor from Temistocles Marcelos, Executive Secretary, Brazilian Forum of NGOs and Social Movements for the Environment and Development, Brasilia.

²⁵ The Stern Report, for example, section 25.2, “Understanding deforestation”, p.605 ff. In section 9.4, p.244, the Stern Report also notes that: “...emission savings from avoided deforestation could yield reductions in CO₂ emissions for under \$5/t CO₂...”. For planting new forests Stern quotes a cost of around \$5 - 15/t CO₂.

²⁶ The Stern Report, section 9.4, p.244, notes that: “Almost 20% (8 GtCO₂/year) of total greenhouse-gas emissions are currently from deforestation.”; and that: “An IPCC report in 2000 estimated a technical potential of 4-6 GtCO₂/year from the planting of new forests alone between 1995 and 2050...”. Current total global greenhouse-gas emissions are about 45 GtCO₂/year [Stern uses “GtCO₂” to mean all greenhouse-gases, expressed in terms of the equivalent amount of CO₂] (Stern Report, section 7.2, p.198).

²⁷ “An old fuel for the future: bio-ethanol offers a way forward”, *Guardian Money*, p.3, 31/3/07.

²⁸ “Sweden, Oilseeds and Products: Nordic/Baltic Biofuels Report 2006”, Global Agriculture Information Service, accessed online on 2/4/07, at www.fas.usda.gov/gainfiles/200604/146187357.pdf.

²⁹ It should also not be forgotten in any evaluation exercise that detritus may be transported by rivers and deposited elsewhere.

³⁰ E.g., “A Look Back at the U.S. Department of Energy’s Aquatic Species Program: Biodiesel from Algae”, p.250, accessed online on 31/3/07 at www1.eere.energy.gov/biomass/pdfs/biodiesel_from_algae.pdf.

³¹ See, for example, “Hybrid Vehicles Gain Traction”, Joseph J. Romm and Andrew A. Frank, *Scientific American*, April 2006.

³² “The Promise of Energy Biosciences”, 7/2/07, Steven E. Koomin, Chief Scientist, BP plc, 5th Annual Lecture Series in Sustainable Development 2007, Centre for Sustainable Development, Cambridge University Department of Engineering.

³³ See, for example, the NYT article, “Taking Control of Electric Bill, Hour by Hour”, 7/1/07, accessed online on 3/4/07, at <http://query.nytimes.com/gst/fullpage.html?res=9E00E4DA1530F93BA35752C0A9619C8B63>.

³⁴ The “European Commission”, quoted in “Biofuel raises global dilemmas”, by Jorn Madslie, BBC, accessed online on 1/4/07 at <http://news.bbc.co.uk/1/hi/business/4603272.stm>.