Perspective

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Biofuels and indirect land use change effects: the debate continues[ϕ]

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Abstract: While debate on biofuels and bioenergy generally has sparked controversy over claimed greenhouse gas emissions benefits available with a switch to biomass, these claims have generally not taken into account indirect land use changes. Carbon emissions from land that is newly planted with biocrops, after land use changes such as deforestation, are certainly real – but efforts to measure them have been presented subject to severe qualifications. No such qualifications accompanied the paper by Searchinger *et al.* published in *Science* in February 2008, where the claim was made that a spike of ethanol consumption in the USA up to the year 2016 would divert corn grown in the USA and lead to new plantings of grain crops around the world to make up the shortfall, resulting in land use changes covering 10.8 million hectares and leading to the release of 3.8 billion tons of greenhouse gas emissions in terms of CO_2 equivalent. These emissions, the paper argued, would more than offset any savings in emissions by growing biofuels in the first place; in fact they would create a 'carbon debt' that would take 160 years to repay. Such criticism would be devastating, if it were valid. The aim of this perspective is to probe the assumptions and models used in the Searchinger *et al.* paper, to evaluate their validity and plausibility, and contrast them with other approaches taken or available to be taken. It is argued that indirect land use change effects are too diffuse and subject to too many arbitrary assumptions to be useful for rule-making, and that the use of direct and controllable measures, such as building statements of origin of biofuels into the contracts that regulate the sale of such commodities, would secure better results. © 2009 Society of Chemical Industry and John Wiley & Sons, Ltd

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Introduction

The rise of biofuels has sparked intense interest, both public and scientific, concerning energy issues, agricultural issues and of course environmental issues, particularly global warming.[*]

The debate over biofuels has largely turned on the validity of claims made for their saving of greenhouse gas (GHG) emissions. Biofuels would be carbon-neutral (in principle) if all the carbon released through combustion as fuel were

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[*] The literature on biofuels is now immense. For a recent authoritative survey of the issues by the United Nations Food and Agriculture Organization, see Ref. 1.

[ϕ] This article was published online on April 17, 2009. An error was subsequently identified. This notice is included in the online and print versions to indicate that both have been corrected [May 1, 2009].

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drawn from carbon absorbed by the plants during photosynthesis. But in practice, of course, fossil fuels are used at various stages in the life cycle of biofuels, with different results depending on where the boundary of the system to be analyzed is drawn.

One way of drawing such boundaries takes into account not just the life cycle effects of growing the biofuel crops and harvesting and processing the product, but deforestation or conversion of grazing land to crop cultivation, induced by the expansion of biofuels demand. These are known as indirect land use change (ILUC) effects, and they have come under particular scrutiny in the past year. No-one denies that ILUC effects are real. The issue is rather whether they can be measured, and, if so, whether they can be quantified in a form that could underpin regulatory measures designed to safeguard sustainability.

A paper published in *Science* in February 2008 stands out in this regard, for the bold and unqualified form of its pronouncement.[2] In a paper co-authored by many of the participants in US debates and coordinated by Tim Searchinger, of the Woodrow Wilson School at Princeton University, the claim is made quite unambiguously that if ILUC effects are quantified in relation to a hypothesized spike in US corn ethanol consumption of 56 billion liters above projected levels up to the year 2016 (the goal for biofuels set by the US Congress) then the impact of the ILUC triggered around the rest of the world would be the release of a further 3.8 billion tonnes of carbon dioxide equivalent (CO_2 equivalent) into the atmosphere. These GHG emissions would be over and above direct effects caused by the combustion of the ethanol.

Clearly if the Searchinger *et al.* calculations are valid, then they would constitute an indictment of biofuels policy in the USA and by implication, around the world. The criticism would be devastating. But are the claims valid – or even plausible?

This is an important question, because already the Searchinger *et al.* results have set in motion deliberations by the Environmental Protection Agency (EPA) in the USA and by the EU in Europe over inclusion of requirements to reduce life cycle GHG emission standards in environmental regulations governing biofuels. For example, the EPA is debating rule-making pursuant to the 2007 Energy Independence and Security Act (EISA) where the reductions in GHG emissions produced over life cycle calculations are required to include indirect as well as direct emissions. So the issue is where to draw the system boundary for life cycle analysis and how to address ILUC effects within the new system boundary. Apart from industry voices opposing such moves, many are concerned that this is taking regulatory action too far, and that the science underpinning such actions, including the ILUC calculations of authors such as Searchinger *et al.*, cannot stand the weight being placed upon them.[†]

In this paper we subject the Searchinger *et al.* calculations to critique, not from the perspective of the methodology adopted (the source of most critiques to date) but from the perspective of the assumptions used and the impact these have on the findings. Our aim is to evaluate the assumptions utilized and their plausibility, both to test whether the specific calculations engaged in by Searchinger *et al.* warrant the attention they have received, and in a wider sense to ask whether ILUC calculations are sufficiently robust and scientifically grounded at this stage to undergird regulatory action.

Outline of the Searchinger *et al.* approach

The Searchinger *et al.* paper has a very particular approach to calculating ILUC due to growing biofuels. Basically it takes an anticipated ‘spike’ in US ethanol consumption of 56 billion liters (corresponding to the Congressional alternative fuel mandate of 30 billion gallons), achieved by 2016, and assumes that all this extra ethanol will be generated by growing corn in the USA.[‡]

It then posits indirect land use effects in terms of extra hectarage that will have to be planted in other countries to make up for the diversion of corn to ethanol in the USA, using a set of partial equilibrium, non-spatial econometric models developed at the Center for Agricultural and Rural Development (CARD) and the Food and Agricultural Policy Research Institute (FAPRI) of the Iowa State University to

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[†] See for example letter from Bruce Dale and others to the Administrator of the EPA.[3]

[‡] Actually Searchinger *et al.* use a spike of 56 billion liters above projected levels, which are also projected to reach 56 billion liters by 2016 – so the spike is actually 112 billion liters. It is of course highly improbable that US corn-based ethanol production will ever reach that level, since alternative sources (such as lignocellulose) and imports are likely to substitute for domestic corn-based production.

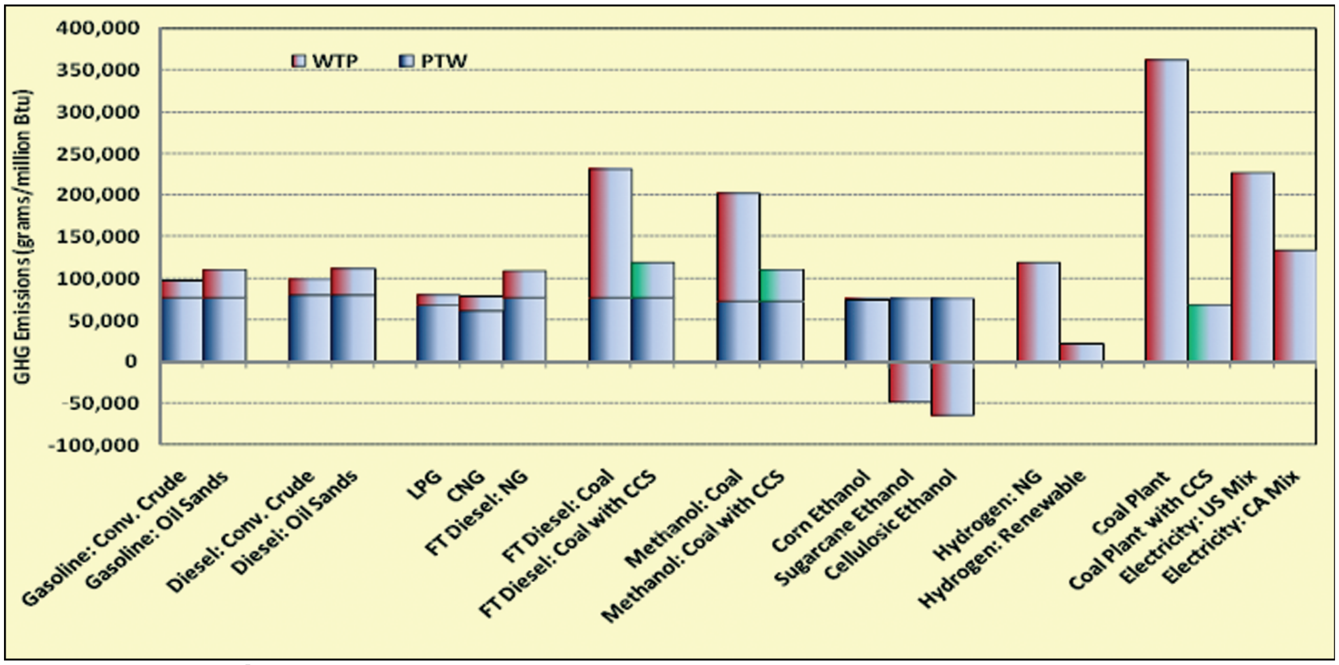
do so. The calculation using the CARD/FAPRI models that results is reported as showing that 'an ethanol increase of 56 billion liters, diverting corn from 12.8 million ha of US cropland, would in turn bring 10.8 million ha of additional land into cultivation. Locations would include 2.8 million ha in Brazil, 2.3 million ha in China and India, and 2.2 million ha in the United States'.[2]

Based on these new posited plantings, the Searchinger *et al.* paper assumes that land use changes (deforestation) would be triggered, based on the changes observed in the 1990s in countries such as China and India – as reported by Houghton,[4] also a co-author of the paper, and maintained in a database held at Woods Hole Research Center. These land use changes induced by the planting of extra grain crops would then trigger release of carbon sequestered both in vegetation and in the soil, with a conversion factor of 351 metric tonnes of CO_2 equivalent released per converted hectare [Correction made here after initial online publication]. On the basis that 10.8 million ha are newly planted, this results in calculated emissions of 3.8 billion tons of CO_2 equivalent GHG emissions attributable as the indirect effect of meeting a spike in ethanol consumption in the USA of 56 billion liters.

No margins of error are reported in the Searchinger *et al.* paper, and there is no discussion of the assumptions utilized and the degree of their validity. It is a flat result: if there is to be a spike in consumption in the USA of 56 billion liters over and above projected consumption up to the year 2016, then it will lead through ILUC around the rest of the world to the dumping of 3.8 billion tonnes of extra CO_2 equivalent GHG emissions into the atmosphere. Such a 'carbon debt' would only be discharged by the carbon-utilizing effects of biofuels (the carbon absorbed by the plants as they grow) after 160 years.

The real target of the Searchinger *et al.* paper would appear to be the model of US ethanol production developed by the Argonne National Laboratory in the USA. Researchers at Argonne have developed a model for biofuels production and consumption in the USA that takes full life cycle analysis (LCA) issues into consideration, as well as some (small) attention to land use changes. This is known as the GREET (Greenhouse Gases, Regulated Emissions and Energy use in Transportation) model. Results generated by GREET have been consistently in favor of ethanol as a fuel source, when contrasted with other alternative fuels – as shown in Fig. 1.[§]

[§] Based on GREET, ethanol is the only fuel sources which has a negative GHGs emission (see also the sample results shown in GREET's webpage http://www.transportation.anl.gov/modeling_simulation/GREET/sample_results.html).



Source: adapted from Wang.[5]

Figure 1. Well-to-wheels GHG emissions of different transportation fuel options.

Figure 1 reveals that of the liquid fuels considered, only sugarcane ethanol and cellulosic ethanol have negative GHG emissions. The GREET model includes GHG emissions due to land use change into its fuel cycle analysis; the assumptions and default values of GHGs emission due to land use change vary largely depending on plant types and market shares of ethanol feedstock as discussed below.[6] Concern over effects from ILUC around the world (such as deforestation in Indonesia) have led to more ambitious attempts to capture and calculate such ILUC effects. This is where Searchinger *et al* enter the picture.[2]

Our approach in this perspective is to retrace the steps employed by Searchinger *et al.* (insofar as it is possible to replicate their calculations, many of which are not transparently accessible) to reveal the underlying assumptions involved. We subject these assumptions to the scrutiny and argument that Searchinger and his colleagues did not provide.

The Searchinger *et al*. calculations – steps followed and models and data employed

The Searchinger *et al.* approach to quantifying ILUC is a very particular kind of analysis. In place of considering decisions to plant biofuels directly, wherever such decisions might be taken, the authors confine their discussion to a US-centered decision to increase corn-based ethanol consumption by a 'spike' and then consider the ILUC triggered around the world as farmers in China and India, for example, are induced to make fresh grain plantings to make up for the shortfall induced by diversion of corn to ethanol in the USA. Thus the ILUC discussed are not only 'indirect' in the sense that they are induced by direct decisions to plant corn in the USA, but indirect as well in that they do not concern other farmers' decisions to plant biofuels, but rather their decisions to plant grain crops induced by the hypothesized diversion of corn to ethanol in the USA.

These approaches are 'particular' because they leave out of account such obvious points as that the real concerns expressed over land use changes deal with decisions to plant biofuel crops in countries like Brazil and India. But the Searchinger *et al.*'s strategy to calculating ILUC effects ignores such issues, since it is focused exclusively on US corn ethanol production, leaving biofuel production in other countries such as China, India or Brazil out of consideration. Moreover, regulatory decisions that would appear to be highly relevant to the discussion, like the stipulation of the US Congress that no more than half of the anticipated spike in ethanol production should come from corn, or China's decision in 2008 to ban the diversion of corn grown in China to production of ethanol, and which would appear to meet the concerns of food *vs* fuel head-on, are ignored in the Searchinger *et al.* approach. With these caveats in mind, let us analyze the calculation strategy employed by Searchinger *et al.* in detail.

The authors take a validated econometric model of the US agricultural system (that developed for US commodities by FAPRI/CARD at the Iowa State University) and subject it to an impulse in the form of a 'spike' in US demand for corn-based ethanol of 56 billion liters over projected levels up to the year 2016. The econometric model which has been deployed in earlier calculations to estimate land use requirements associated with growth in ethanol production in the USA[7,8,9] is used to generate the 'impulse response' created by this spike, in the form of a rise in prices (corn prices rise by 40%, wheat by 17% and soybeans by 20%) and changes in acreage in the USA as well as changes predicted internationally through the CARD international ethanol analysis, the FAPRI international sugar model and modified versions of the FAPRI US and international crop models, which are not transparently accessible.**

These are linked in ways that are not made clear in the Searchinger paper (or in the supplementary material) to models that link US crop acreages and prices with crop acreages in other countries such as China, India and Brazil. The supply and demand elasticities utilized are based on historical figures, especially 'the high price regime [in the commodity markets] of the past 3 years';[2] but they do not necessarily reflect the dynamics of commodity price changes in the future, for example, in the years leading up to 2016. The result reported is that the spike of 56 billion liters in US demand up to the year 2016 translates into diversion of corn in the US – diverting corn from 12.8 million ha of US cropland to ethanol and the deficit in corn in world markets being made up by new plantings of corn and other grains

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**Correspondence with researchers at the CARD/FAPRI Center reveals that the models utilized are not publicly accessible.

around the world. The complete listing of responses to the 56 billion liter spike is given in Table C-1 of Appendix C in the supplementary material.[2]

Having established the impulse response in the form of compensatory grain plantings around the world, bringing in new plantings, the next step of the Searchinger *et al.* methodology is to assess how land use changes will be triggered by these fresh (hypothesized) plantings. It is assumed that all the compensatory grain plantings will trigger land use changes, converting land that is either forest or grassland into cropland and thereby releasing the carbon that has been sequestered. Using data from Woods Hole Research Center on conversions recorded in China, India *et al.* during the 1990s, the new plantings reported in Table C-1 are then allocated to so many ha converted from forest in China, so many ha converted from grassland in China, etc.[2] Appendix D of the supplementary material details the methodology as utilizing the FAOSTAT database, as well as making some arbitrary assumptions such as that when land is converted to cultivation, there occurs a loss of 25% of the carbon stored in the top meter. Data from different regions reported in Tables D-1 to D-9 are then used to drive the calculations of land use changes that are reported in Tables D-11 and D-12. [2] Again the details of the models used for these calculations are suppressed, and only the results of the impulse response calculation are reported.

Finally the land use changes calculated are converted to GHG emissions, as reported in Table E-1 of Appendix E of the supplementary material, which builds on Tables C-1 and D-11 and D-12. [2] The land use changes in each world region are reported in terms of hectares (totalling 10.8 million ha) and converted to total GHG emissions through using conversion factors of CO_2 equivalent (metric tons per hectare). The total emissions are calculated to be 3.8 billion tons CO_2 equivalent induced as a result of the spike of 56 billion liters in US ethanol consumption. As the paper proper reports the matter: 'Our method yielded an average GHG emission of 351 metric tons per converted hectare (CO_2 equivalent)'.[2]

This is the result that the authors then contrast with the results without major land use changes reported by Argonne National Laboratory, with the GREET model, which predicts a benefit in terms of GHG emissions of 57 grams CO_2 equivalent per kilometer driven. So the final comparison is made after taking the overall GHG 'cost' derived from the land use change due to the spike in ethanol consumption, to be then set against the 'benefit' of driving on ethanol as calculated by Argonne National Laboratory. The final result is reported as follows: 'Factoring in our 316 g/km charge for land use change results in an increase of GHGs when using ethanol instead of gasoline to 536 g/km compared to 221 g/km'.[††]

Note that the convoluted procedure involved in the Searchinger *et al.* approach is partly dictated by the choice of models to be utilized, namely the CARD/FAPRI models of US agricultural commodities. These models do not include different land use possibilities but only consider land already under crops; hence the roundabout procedure of then bringing in the ILUC induced by the diversion of corn in the USA to ethanol. Other approaches do not suffer from this defect. We shall discuss below alternative approaches where land use changes worldwide are directly modelled. [10,11,12]

Note, too, that no model is provided in the Searchinger *et al.* paper together with parameters used, which would enable others (like ourselves) to replicate the results and probe the workings of the model.[‡‡] Instead there are simply references to the models employed at CARD (references which fall well short of full specification) and results only are reported. This falls somewhat short of the scientific method where results reported are supposed to be replicable by other parties.[§§]

Testing the assumptions

The assumptions made by Searchinger *et al.* in actuality determine the overall direction of the results. We probe them through the following six steps.

[††] Searchinger *et al.* p.9 in Supporting Online Material.[2]

[‡‡] New results reported using the same suite of models are those on projected US ethanol production in Tokgoz *et al.*[13] and on the effects of removing distortions in the US ethanol market.[13]

[§§] We do recognize that this is becoming standard practice where complex models are utilized, and that further details on the workings of the models employed are available in subsequent publications such as Elobeid and Tokgoz[14] or Tokgoz *et al.*[13]– as the authors have indicated to us (Tokgoz, 2008, private communication). But our point is that this still falls well short of providing public access to the models so that alternative assumptions can be tried and tested – as is possible, for example, with the GREET model.

Direct plantings of biofuels crops around the world are ignored, and instead a spike in US corn-based ethanol is considered as trigger

The most straightforward way to test ILUC effects of biofuels would be to pose changes in land use in countries such as Brazil and Indonesia and ask to what extent these land use changes are actually caused by biofuels. This directly addresses the real concerns that are reasonably and realistically held – and also reveals how difficult it is to answer such concerns in anything like a scientifically rigorous manner. Attempts along these lines have been reported as discussed below.[10–12] Clearing of tropical rainforest in Indonesia is a case in point. It is a process universally deplored, and causes terrible air pollution throughout Southeast Asia when the burning off of cleared land is taking place. An adequate measure of the disturbance of sequestered carbon is clearly needed, and backed by some incentives granted under the Kyoto treaty on global warming or at least by its successor. But these issues go well beyond the narrow confines of Searchinger *et al.* Instead of addressing these real issues, the Searchinger *et al.* approach is to discuss a spike in ethanol consumption in the USA, ignoring all these other direct sources of land use changes driven by planting biofuel crops.

The US spike is met exclusively by growing corn – but other ways of meeting the US spike, all involving fewer GHG emissions, are ignored

Having confined its consideration of ILUC effects solely to a spike in US ethanol consumption, the Searchinger *et al.* approach then reinforces this approach by excluding all ways of meeting that spike other than the growing of corn in the USA itself. A global problem is thus reduced to a US issue, and then to a consideration of what most observers agree would be the worst possible solution within the USA itself. All other potential biocrops within the USA (as considered within the GREET model for example) are ignored in the Searchinger *et al.* approach.

In the GREET model, a range of feedstock options for ethanol production is available for analysis – including corn, woody biomass, herbaceous biomass, corn stover, forest residuals (all produced from US sources) and sugarcane for ethanol produced in Brazil (but transported and consumed in the USA). In GREET, the assumptions and default values of GHG emissions due to land use change vary largely depending on plant types and market shares of ethanol feedstock.[6***] Our simulations with different market share options confirm that the results of CO_2 emissions due to land use change, Well-to-Pump (WTP) GHG emissions, and Well-to-Wheel (WTW) GHG emissions will vary significantly if ethanol feedstock sources change from the original default value, i.e., ethanol production with 100% of corn, to some alternative. Simulation results of our scenario analysis are shown in Table 1.

The results clearly show that corn is the most unfavorable source for ethanol production in terms of GHG emission due to land change (WTP emissions and WTW emissions). It is precisely this assumption that 100% of ethanol production in the USA is based on corn that was used in the Searchinger *et al.* study and which greatly underestimates the positive effects of ethanol production possibly from other sources.

The US spike met entirely within the USA – without regard to trade (such as half of the spike being met by Brazilian sugarcane ethanol and imported into the USA)

Even granting the validity of considering land use changes triggered solely by a spike in ethanol consumption in the USA, the assumption that such a spike would be met by diversion of corn to ethanol, and solely by corn grown in

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[***] In the HELP function of GREET, we found more detailed explanations as follows.

'CO_2 emission due to land use change by corn farming is the emission of CO_2 caused by the change in land use required to farm corn as a feedstock for ethanol production. The new land is assumed to be some type of pastureland. Based on USDA simulations, only a small fraction of corn for ethanol production will be probably produced from new land, while the majority of the corn will be produced from existing corn farms.'

'[For] CO_2 emission due to land use change resulting from biomass farming for cellulosic ethanol production. The new land is assumed to be either idle or pastureland prior to biomass farming. Biomass production per unit of land area is generally different for different crops and vegetation. Cultivating fast-growing trees such as hybrid poplars (woody biomass) and switchgrass (herbaceous biomass) have land use impacts. The amount of aboveground standing biomass, the amount of underground biomass (i.e., roots), and the organic carbon content of the soil will increase, and these changes will lead to CO_2 sequestration, in addition to the amount of carbon contained in the biomass harvested for cellulosic ethanol production.

Table 1. Results of the scenario analysis: different market share options.

Ethanol feedback shares	CO_2 Emission due to land use change by farming (g/bushel for corn or g/dry ton for others) #	Well-to-Pump GHG Emission (Btu per mm Btu of Fuel)	Well-to-Wheel Emissions (Btu per Mile):		
			Feedstock	Fuel	Vehicle operation
100% Corn	195	983 (CO2 emission: -10,560)	-182	186	369
100% Wood Biomass	-112500	-59,920	-291	-1	369
100% Herbaceous	-48500	-42,125	-220	16	369
100% Corn Stover	0	-45,170	-234	15	369
100% Forest Residuals	N/A	-37,574	-229	47	369
100% Sugar	N/A	-32,761	-199	40	369

Year: 2017; Ethanol Blend Level: high-level blend (50–90% by volume with gasoline).
#: positive values imply emissions and negative values imply sequestration.
Source: Authors' calculation using GREET v.1.8b.

the USA, without regard for the possibility that some of the US ethanol required would be imported, for example, from Brazil where sugarcane would be the crop of choice, seems indefensible. The Searchinger *et al.* consideration of ILUC is triggered solely by extra grain plantings occurring around the world induced by the deficit in corn in the USA caused by diversion to ethanol. But it is much more straightforward and realistic to consider the case where a proportion of the ethanol consumed in the USA is imported, for example, from Brazil, and that this ethanol might be produced not from corn but from the crop best adapted to conditions in Brazil, namely sugarcane. It is indeed striking that the Searchinger *et al.* calculations concern global effects of ethanol consumption without ever considering the world's premier crop for such production, namely sugarcane. Admittedly Searchinger *et al.* insert a qualification to the effect that the extraordinary productivity of biofuels grown in Brazil 'deserve further study' – but this is as vague as it is unhelpful, given that such 'further study' would presumably have to start from the narrow confines of the Searchinger *et al.* assumptions.[†††]

Of course, we understand why Searchinger *et al.* might have wished to avoid such trade issues. If realistic assumptions as to possible imports of ethanol grown from sugarcane are to be included in the calculations, then what level of trade should be included? Should it be 1% imports to reflect past trends, when imports from Brazil are practically banned by high tariffs and subsidies? Should it be 25% or even 50% to reflect probable shifts in the trade balance between now and the year 2015?[15] To raise such issues is only to underline how indeterminate the calculations engaged in by Searchinger *et al.* really are.

The Searchinger *et al.* calculations of carbon release are based on trends recorded in the 1990s but are projected forward up to 2016

While the hypothesized carbon release in the Searchinger *et al.* calculations is supposed to take place from land use changes around the world in the years 2010 to 2015, the data used come from measurements recorded during the 1990s and held at the Woods Hole Research Center in the USA. These data have been reported in prior publications by Houghton,[4] one of the co-authors of the study. These are based largely on results recorded for India and China during the 1980s and 1990s, when land use changes were driven by rapid industrial growth and were subject to little or no regulatory control. However, the latest study suggests that the Woods Hole data overestimate the effect of net land use emissions. The Intergovernmental Panel on Climate Change (IPCC) takes a different view. In its latest report, the IPCC estimates that the trends of net land use emissions are expected to fall dramatically, as shown in Figure 2 which

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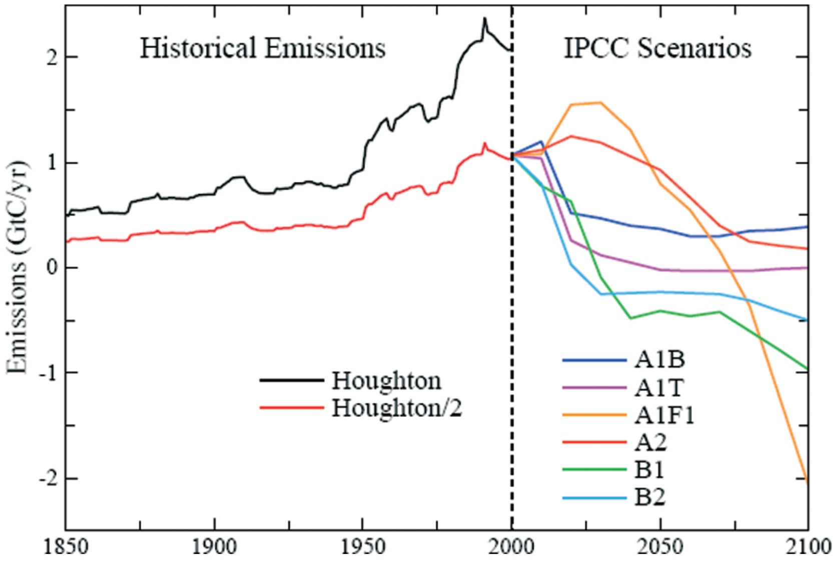
[†††] A subsequent paper by two of the co-authors, Elobeid and Tokgoz[14] explicitly discusses ethanol trade between the USA and Brazil, characterizing it as a desirable outcome for both countries. But public discussion of the Searchinger *et al.* approach to ILUC effects continues to ignore the trade option.



Left side: estimate by Houghton of historical net land-use CO_2 emissions, and a 50% reduction of that estimate. Right side: IPCC scenarios for land use CO_2 emissions.[16]
Source: adapted from p. xiii, the supporting material of Hansen *et al*.[18]

Figure 2 Net Land Use Change Emissions.

is adapted from the IPCC report. These alternative views of carbon release from land use change are ignored in the Searchinger *et al.* approach.

Improvements in biomass yields around the world are not considered

Yields of crops, whether of corn or other biofuel crops, are critical to land use considerations, yet they are given very odd treatment in Searchinger *et al.* If improvements in US corn yields accelerated between now and 2016, so that the 'spike' of 56 billion liters could be met by existing croplands, then there would be no land use changes to consider in the Searchinger *et al.* approach, and the whole case against US corn-based ethanol would collapse. So Searchinger *et al.* adopt a more conservative position, and claim that they assume that 'increased ethanol and higher prices spur enough yield increases beyond current trends to supply 20 percent of the replacement grain'.[2] We have to take them at their word for this, since the calculations involved are inaccessible. But later in the paper, Searchinger *et al.* make the astonishing statement that: 'Even if excess croplands in the US or Europe become available because of dramatic yield improvements beyond existing trends … biofuels would still not avoid emissions from land use change'.[2] This is because 'truly excess croplands would revert either to forest or grassland and sequester carbon'.[2] So apparently it doesn't matter what the yield improvements might be, according to Searchinger *et al.* If they are small, then more lands will be converted to grain, thus releasing carbon. If the yield improvements are large, then fewer lands will be needed for agriculture and some can even revert to forest or grassland thus sequestering carbon (which might be characterized as negative land use change). But the real issue is that yield improvements reduce the need for land use changes, period. In countries other than the USA, enormous efforts are expended to improve biofuel crop yields, such as in Brazil, where yield improvements in sugarcane of upwards of 3% per year over the past 30 years have been achieved, thanks to intense knowledge inputs from R&D institutions such as EMBRAPA.[17] In African countries, agricultural yields remain depressingly low, and if they were brought up to Brazilian levels (or even to half the Brazilian levels) then the increased demand for bioethanol around the world could be met by these African countries alone, just through their increased yields – if global trade in biofuels were freed from the tariffs and subsidies imposed by the USA and Europe. But these possibilities are completely ignored in the Searchinger *et al.* approach.

The US spike leads to indirect effects around the world without regard to regulatory limits (even in the USA)

Commentators have already pointed to the fact that the Searchinger *et al*. assumption of a spike of 56 billion liters over existing trends is inappropriate, in the face of US Congressional statements on the record that no more than 50% of the spike should be met by corn-based ethanol.[19] When considering ethanol consumption up to the year 2016, it is surely relevant to include such Congressional strictures. And around the rest of the world, there are comparable regulatory considerations, either in force or being discussed, to limit the degree to which ethanol can be produced from corn. The strongest such regulatory sanction is that imposed in China, where the National Development and Reform Commission (NDRC) has declared that 'no corn grown in China is to be used for ethanol production'. This is to avoid any future conflict between food *vs* fuel in China. Now this Chinese regulatory intervention is surely relevant to any reasonable consideration of ILUC in China – yet the form of the Searchinger *et al.* assumptions exclude it from consideration. The Searchinger *et al.* approach is to consider Chinese plantings of corn and other grains as simply making up for the deficiency in world grain markets caused by diversion of corn to ethanol in the USA. This peculiar way of viewing the global situation thus allows the Chinese regulations to pass unnoticed by the Searchinger *et al.* calculations. Moreover, even within the scope of the Searchinger *et al.* approach, it is relevant to ask whether Chinese policy is encouraging or discouraging conversion of forest land and grassland to agricultural use. In fact, the evidence points to the fact that China is discouraging such trends, and promoting afforestation and conversion of marginal croplands to grassland. For example, one of the programs set up by the Chinese Government, known as the 'Grain for Green' or 'Sloping Land Conversion Program' (SLCP), is the largest reforestation program in the developing world, with the goal of converting 14.67 million hectares of cropland to forests by 2010.[20,21] This too, while directly relevant to the Searchinger *et al.* approach, is ignored.

Alternative approaches

Searchinger *et al.* do not discuss alternative approaches, but actually several have been discussed in the literature and have resulted in published results remarkably at variance with those published by Searchinger *et al*. For example, one approach would be to take actual plantings of biofuel crops around the world, as reported by FAO, to calculate the impact of a 'spike' in consumption in the USA or elsewhere. This was the approach adopted by Gurgel *et al.*[10] and others such as Ahammad and Mi[11] and Golub *et al.*[12] Two versions of the model are employed in Gurgel *et al.,*[10] one allowing unrestricted conversion of natural forest and grass land to cropland and another based on observed land supply response. Both models are simulated for two alternative future scenarios, i.e., the scenario of business-as-usual (BAU) and the policy scenario where a global effort would be mounted to limit global cumulative emissions to about 1490 billion metric tons (bmt) from 2012 to 2050 (and 2834 bmt from 2012 to 2100). Gurgel *et al.*[10] estimate that in the first scenario the global biofuel production will be below 16 Exajoules (i.e., about 68 billion liters of ethanol)[‡‡‡] until 2040 and in the second scenario the global biofuel production will be around 70 Exajoules (about 300 billion liters of ethanol) in 2040 – both exceeding the 'peak' considered by Searchinger *et al.*

Although the model of Gurgel *et al.* [10] and that of Searchinger *et al.* both start with a projection of a large amount of biofuel demand, significant differences can be observed between the results of land use change in the two approaches. For example, in the calculation of Searchinger *et al.,* the spike of 56 billion liters in US ethanol demand is modelled as being produced from corn planted in 12.8 million ha of US cropland. The increase in demand of US corn in turn triggers land use change elsewhere, with most increases of cropland occurring in the China, India and Brazil as well as in the USA itself (see Table C-1 in the Supporting Material[2]). However, according to the estimate of Gurgel *et al.*,[10] the overwhelming majority of biofuel production will occur in Latin America and Africa with little being expected in the USA. The simulation of Gurgel *et al.*[10] further suggests that countries such as China and India are likely to meet the domestic demand of biofuels through international

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[‡‡‡] We use the energy unit conversion factors available at http://bioenergy.ornl.gov/papers/misc/energy_conv.html, which suggests that one liter of ethanol provides about 23.4 MJ of energy, or 23.4 * 10^{-12} Exajoules (EJ)

trade. Therefore the land use would not change significantly due to demand of biofuels in these countries.

Other economic modeling works also produce results at variance from those in Searchinger *et al.* For example, using five different variants of the Global Trade Analysis Project (GTAP) model at Purdue University, Golub *et al.*[12] project 'a strong move towards afforestation in response to increased demand for forest products worldwide, including ASEAN, South Asia and the Rest of the World – three regions which have experienced extensive deforestation in the past few decades'. It is projected by all five models that land use in China, for example, moves from agricultural crops to pasture (for ruminants) and forestry in the next 15 years, a conclusion sharply at odds with that of Searchinger *et al.* It should be noted that heterogeneity of land, and thus some degree of limit in land mobility, was taken into account in the models of Golub *et al.*[12] a rather more realistic assumption than the one employed in the analysis of Searchinger *et al.*

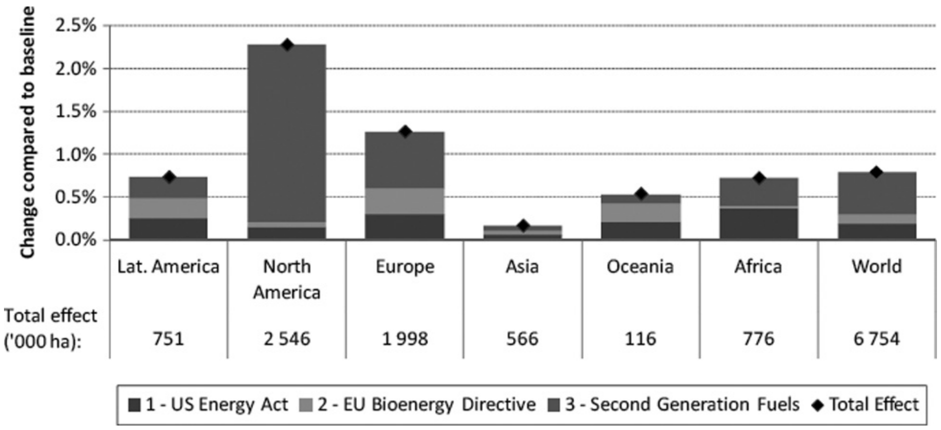
Actually there are available alternative views as to the carbon released by changes in land use by bodies as reputable as the IPCC (above) and the OECD. These make much more reasonable assumptions than employed in Searchinger *et al.*

The OECD, for example, estimates that the US EISA program and the new EU Directive on Renewable Energy (DRE) together are expected to increase use of ethanol by some 17% by 2013–2017, i.e., 19.4 billion liters.[22] However, the impact on total crop area in the world is much more modest compared with the calculation of Searchinger *et al.*, rising by less than 1% from the baseline of about 6.8 million ha, as shown in Fig. 3. Most of the increase will occur in North America and little change in Asia.

For its part, the EU is also developing alternative estimates of ILUC effects that will no doubt be very different from those offered by Searchinger *et al.*

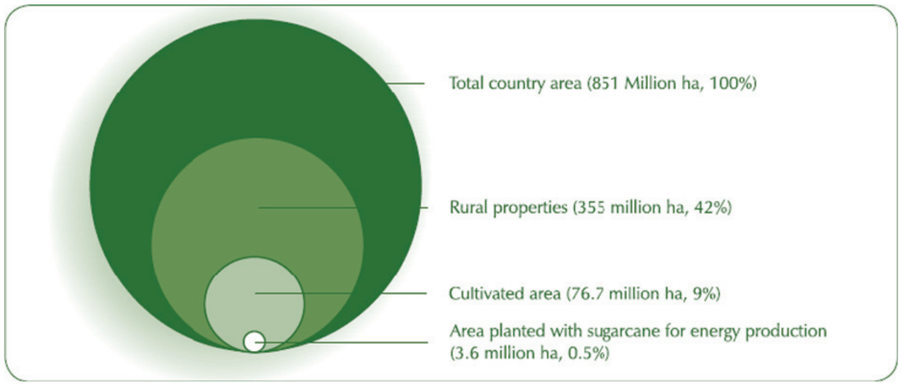
In countries directly influenced by these considerations, such as Brazil, stringent efforts have been made to accurately assess the real land use change effects that have occurred as a result of expansion of biofuel crops. In Brazil, around 22 billion liters of bioethanol were produced on 3.6 million ha of area in 2007/2008, accounting for a very small proportion of the cultivated area and the total rural properties, as shown in Fig. 4.

Most of Brazil's current sugarcane is grown in the southeast of the country, in Sao Paolo state. It is widely agreed in Brazil that the country's present efforts could be doubled or more, planting perennial crops (sugarcane) in areas of degraded pasture land, thus enhancing carbon sequestration. Indeed the 'peak' considered by Searchinger *et al.*, namely 56 GL, could be easily met in Brazil alone from 9.0 million ha, or just over double the present planting of sugarcane. It is this fact that shows the illogic of the Searchinger *et al.* approach, considering one very unlikely hypothetical alternative up to 2016 (producing all of the 56 GL peak from corn grown in the USA) as opposed to much more realistic and rational alternatives such as producing the peak from sugarcane ethanol in a country where degraded lands would store more carbon under perennials than in their current state.[17]



Source: adapted from OECD.[22]

Figure 3. Impact of 19 billion liters extra ethanol production on total crop area, 2013–2017 average.



Source: Adapted from BNDES and CGEE (p.189).[17]

Figure 4. Land use in Brazil, 2007/2008.

In fact, the kind of ILUC effects that form the basis of the calculations offered by Searchinger *et al.* (calculations that are not in fact replicable by other scientific laboratories since key models and relationships and parameters are not specified) simply open up the prospect of endless scientific debate and controversy. There can never be a 'definitive' calculation of ILUC effects since such effects depend, as we have shown in this perspective, crucially on the kinds of assumptions made, which in turn make all kinds of assumptions as to regulatory impositions and world trade developments.

This is why basing national rule making on LCA of biofuels, imposing certain standards or measures based on LCA on biofuels consumed in a certain country or region – as is reportedly under consideration in the USA by the EPA and in Europe by the EU – is ultimately indefensible.

But there is a much more straightforward way of casting the issue, to whose consideration we turn finally.

How to impose direct controls that are workable, measurable and enforceable – for example, through commodity markets

An alternative approach to ensuring that ILUC are factored into world trade in biofuels is to ensure that biofuels traded have some kind of 'proof of origin' attached to them. Thus if there is legitimate concern that biofuels grown in Brazil are having an indirect effect on Amazon land clearing, then ethanol produced from Brazilian sugarcane should carry a tag indicating where in Brazil it was grown. This would enable consumers, and importing countries, to make decisions as to what to consume based on best current scientific evidence.

Now the standard objection to such an arrangement is that biofuels are traded by large commodity traders who blend the fuels from various sources – just as the petroleum companies blend oil from various sources in the final refined product. They argue that to block such blending would be to remove their prime source of competitive advantage. There is clearly some force to this objection.

There is in fact a way around such objections. What if the commodity markets where biofuels are traded impose a condition on the seller to attach an electronic tag or certificate revealing the 'proof of origin' of the biofuel, i.e., where it was grown. A commodity package traded on an exchange would have to carry such certification, just as it is already required to carry certification specifying compliance with certain standards that define the fuel's attributes. If the commodity is blended, then the blended product would have to carry certification of proof of origin of the various source fuels involved. A proposal along these lines is being actively considered by the Environmental Defense Fund in the USA, based on a proposal published by Mathews.[23§§§]

In this way decisions taken by consumers or by importing countries can be reached with full disclosure as to the source of the biofuel, and subject to the best scientific evidence obtained regarding the ILUC effects attributable to biofuels grown in that part of the world. This is a reasonable means of bringing ILUC effects into such decision-making, without making unreasonable requirements on national environmental rule-making procedures that go beyond reasonable scientific requirements.

[§§§] Private communication from DeCicco (2008).

Concluding remarks

The Searchinger *et al.* paper is framed in extremely negative terms that depict all biofuel production taking place in the USA and all derived from corn. It calculates land use change effects through the indirect route of assuming that diversion of corn to ethanol in the USA creates a shortfall that has to be made up by farmers planting grain crops in the rest of the world – rather than assuming that farmers are taking decisions to grow biofuel crops around the world using crops adapted to their environment, such as sugarcane in Brazil. The study then deliberately ignores possible trade effects, such as a proportion of this ethanol spike being met by imports from countries such as Brazil. It even ignores the Congressional cap that was placed on US first-generation corn-based ethanol, which was levied at 15 billion gallons (i.e., half the spike used by Searchinger *et al.*).

Indeed if you wished to put US ethanol production in the worst possible light, assuming the worst possible set of production conditions guaranteed to give the worst possible ILUC effects, then the assumptions chosen would not be far from those actually presented (without argument or discussion of alternatives) in the Searchinger *et al.* paper. This, together with the fact that the paper is not replicable, since the models and parameters used are not accessible, places a question mark over the refereeing procedures used for this paper by the journal *Science*. A paper that seeks to place a procedure in the worst possible light, and refrains from allowing others to check its results, is perhaps better described as ideology than as science.

We do not wish to convey the view that ILUC effects are not important. We hold them to be very important, both for the emerging biosciences and for the planet itself. There is much work to be done in conceptualizing, measuring and drawing the implications from such ILUC considerations, and contrasting these with the threat of devastation to the planet caused by continuing with the fossil fuel option. The Searchinger *et al.* paper is a first but certainly not the last word on these important topics.

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