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Biofuels

Summary: The environmental benefits derived from biofuels results from the plants used to engineer them. Plants take carbon dioxide out of the atmosphere. But it takes land to grow these plants, and using land for biofuels sacrifices other benefits of keeping land in its existing use. New analyses are now showing that the loss of greenhouse gases from direct and indirect land use changes exceeds the other benefits of biofuels over decades. This paper summarizes how the new analyses compare with the old, discusses the reasons for believing this result is reliable despite the uncertainties in detail, and explains that some biofuels, such as those produced from municipal, industrial and agricultural waste, remain viable ways of reducing greenhouse gases. Policies need to focus on biofuels that do not trigger significant land use change.

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THE IMPACTS OF BIOFUELS ON GREENHOUSE GASES: HOW LAND USE CHANGE ALTERS THE EQUATION

by Tim Searchinger, Transatlantic Fellow, The German Marshall Fund of the United States[1]

Greater energy independence and higher rural incomes are some of the goals of biofuel policies, but biofuel backers probably most often cite benefits for global warming. For years, analysts who compared biofuels with gasoline and diesel fuel dueled it out through their lifecycle analyses. A lifecycle analysis compares the emissions of greenhouse gases from all the different stages of producing or using a fuel. After years of competing numbers, a consensus emerged that corn-based ethanol modestly reduces greenhouse gases, biodiesel from soybeans, rapeseed oil or palm oil reduce greenhouse gases more, and ethanol from sugarcane or switchgrass provides the most benefits of all. New studies, including one of which I am a co-author, now find that these analyses left out a critical factor, and that only limited categories of biofuels are likely to reduce greenhouse gases.[2]

What previous analyses left out

Despite the complexity of previous lifecycle analyses, biofuels can reduce greenhouse gases relative to fossil fuels because of their carbon dioxide recycling effect. Carbon dioxide (CO2) is the gas that most contributes to global warming, and when plants grow, they convert carbon dioxide to plant tissue both above ground and in roots. Growing corn, soybeans or switchgrass for a biofuel therefore takes carbon dioxide out of the atmosphere, and when cars or trucks burn biofuels, they return that carbon dioxide to the air. By contrast, when cars or trucks burn gasoline or diesel fuel, they put carbon into the atmosphere that would otherwise remain safely stored underground in crude oil. In the other stages of production, biofuels tend to cause more greenhouse emissions than gasoline, but in previous lifecycle analyses, the carbon removed from the atmosphere by the "feedstock" for biofuels is the key to their edge.

These analyses would be accurate if biofuel producers brought land into existence to grow biofuels. Unfortunately, the world's land already exists. Any productive land dedicated to growing biofuels is land that would otherwise already support plant growth and that probably has supported such growth for years, taking carbon out of the atmosphere and storing it in trees, grasses, roots and soils. If farmers convert forest or grassland to grow biofuels, they have to clear the vegetation, which

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[2] T. Searchinger, "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases When Factoring in Land Use Change," Science Express (Feb. 7, 2008) Searchinger et al.

mostly decomposes or burns, and transfers carbon back to the atmosphere. Farmers also typically plow up the soil, which allows oxygen and microbes to break down much of the carbon long stored in the soil, releasing it back into the atmosphere. If biofuel producers use existing crops or cropland for biofuels, these emissions occur indirectly. So long as people do not reduce the amount of food they consume, farmers will mostly convert other forest or grassland to replace the crops no longer grown, causing greenhouse gas emissions indirectly. Most lifecycle analyses ignored these emissions from land use change entirely, and the small number of analyses that looked at them, made only limited efforts to calculate them.[3]

The reasons for this omission are unclear. Many of the initial analyses took place when biofuel levels were low, and the extent of their impacts on world land uses too small to be visible. The analyses essentially assumed that biofuels would come out of surplus cropland, or croplands that would become available because of steadily rising yields. But even if biofuels were to use "surplus cropland," truly surplus croplands would revert to grassland or forests, sequestering carbon. In that case, using land to grow the biofuels would sacrifice these other carbon benefits, and the analyses should have reflected those impacts. Analysts over time have also tended to look entirely at domestic cropland levels, which in the United States have been roughly stable until recently, and which in Europe have tended to decline until recently. But cropland has aggressively expanded in Latin America and to a lesser extent in Asia and Africa. Incrementally, however small the level of biofuels, when biofuels divert U.S. or European crops, they send a signal through higher prices for worldwide producers to expand. At today's higher levels of biofuels, the effects have become obvious.

Whatever the cause, omitting the emissions from land use change effectively creates one-sided accounting. In effect, most analyses have counted the carbon benefits of using land for biofuels but not the carbon cost. Productive land, whether or not used for biofuels, has carbon benefits. Those benefits can be in the form of carbon storage in forests and grasslands. They can also be in the form of food and feed—carbohydrates, fats and proteins. (Carbon in feed and food tends to return quickly to the atmosphere when we (or livestock) eat them, but if biofuels eliminate this food, we have to replace these benefits for the most part by moving into other carbon-rich lands.) A proper accounting must balance the benefit of using land to grow biofuel feedstocks only to the extent it exceeds the carbon benefit of continuing land in its existing use.

[3] Mark Deluchi undertook the most impressive previous effort as part of a complex, overall life-cycle analysis. His analysis, although impressive, lacked formal agricultural modeling and some of the other data my team was able to use. It also used a complicated, unusual form of discounting to present the impacts, which obscured the true nature of his findings. See discussion in supporting online materials for T. Searchinger et al., cited in footnote two.

Other recent work: Growing attention to land use change

In the last year or so, a number of analyses have highlighted the "potential" of the expansion of biofuels to increase greenhouse gas emissions without calculating the effect. Many studies, otherwise reporting greenhouse benefits quantitatively from biofuels, have included caveats that "expansion" of biofuels could trigger land use changes with greenhouse gas emissions that overwhelmed the benefits.[4] Unfortunately, the quantitative results showing greenhouse gas benefits tended to eclipse these narrative caveats.

One paper in *Science* also pointed out that if land were not used for biofuels, it could typically generate greater benefits through reforestation.[5] That paper should have received more attention, but it still permits the conclusion that biofuels are better than existing land uses even if not the best possible.

A few papers have also started to calculate the relative effect on greenhouse gas emissions of converting specific types of forest or grassland to produce biofuels, and warn that converting these habitats will likely increase emissions. A new paper in *Science*, "Land Clearing and the Biofuel Carbon Debt,"[6] assesses a number of scenarios: (1) palm oil that replaces lowland forest or lowland peat forest in Southeast Asia; (2) soybean biodiesel that replaces Cerrado or rain forest in Brazil; (3) sugarcane that replaces the same Brazilian habitats; and (4) corn ethanol that replaces Conservation Reserve Program lands in the United States. By focusing individually on a number of particular habitats that are prime candidates for conversion, this paper incorporates some important details. For example, it properly calculates that southeastern peatlands will not just lose 25 percent of carbon—a standard estimate for conversion to cropland—but will in fact lose carbon indefinitely as deep peat soils are drained and decompose over time. The paper calculates extremely long periods for paying back the initial "carbon debt"—the years before the savings from biofuels recoup the up-front emissions from land conversion. Biofuels would never payback the palm

[4] Some examples include A.E. Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311, 506 (2006) and its "Supporting Online Material (rael.berkely.edu/EBAMM/EBAMM_SOM-1-0.pdf); R. Zah et al., "Lifecycle Assessment of Energy Products: Environmental Assessment of Biofuels" (Empa Technology and Society Lab, St. Gallen, Switzerland); E. Smeets, M. Jnginger, A. Faaj, A. Walter, P. Dozan, "Sustainability of Brazilian bio-ethanol" (NWS-E-2006-110, ISBN 90-8672-012-9, Universitaat Utrecht Copernicus Institute, State University of Campinas, 2006).

[5] R. Righelato, D.V. Spracklen, "Carbon Benefits bhy Biofuels or by Saving and Restoring Forests," *Science* 317:902 (2007).

[6] J. Fargione, J. Hill, D. Tilman, S. Polasky and P. Hawthorne, "Land Clearing and the Biofuel Carbon Debt," *Science Express* (Feb. 7, 2008).

oil debt on Southeast Asian peatlands and would pay back the carbon debt for soy-based biodiesel produced on Brazilian rain forest only in 320 years. The shortest payback period would be 17 years for sugarcane produced on the drier end of the Cerrado in Brazil.

One particularly interesting result of "The Biofuel Carbon Debt," is that just converting Conservation Reserve Program (CRP) lands in the United States to corn ethanol production would still require a 48-year payback period. These are lands that the federal government pays farmers to plant grasses on. That long payback period is interesting because the authors assume these lands had only 15 years to accrue soil carbon. This calculation probably underestimates emissions from land use change because the authors calculate only the losses of existing carbon, and therefore do not calculate the additional soil carbon those lands would sequester if they remained in CRP use into the future.

> "The [EU biofuel] directive would exclude biofuels produced directly on lands newly converted from forest or grassland. This condition would not solve the problem."

These calculations suggest many biofuels will increase greenhouse gases because they show the imbalance between the savings per hectare of biofuels and the emissions per hectare of mature habitats converted to biofuels. But this kind of study only shows the carbon debt if biofuels are produced out of specific, high carbon lands. It cannot say which lands biofuels will in fact displace. Faced with these kinds of criticisms, biofuel advocates increasingly claim they will avoid the direct use of these carbon-rich habitats and will instead use existing croplands, or unspecified degraded lands.

Just last month, the European Union Transport Ministry proposed a directive that would require each member country to supply 10 percent of its transport fuels from biofuels. But the directive would exclude biofuels produced directly on lands newly converted from forest or grassland. This safeguard would not solve the problem. Instead, it would require that biofuel producers use existing cropland; however, farmers would still plow up new lands to replace the crops for food and feed. Estimating how much and where that will occur is the subject of the study by my team.

Our study: Estimating greenhouse gas emissions from the land use change that is likely to occur

The increases in greenhouse emissions from land use change follow a chain influenced by a variety of economic and ecological factors. It starts with the increased demand for a feedstock, such as corn or vegetable oil, increasing the price. Those price increases cause farmers to switch from producing some crops to others, which reduces those other crops as well and drives up their prices. The price increases cause consumers to buy less food. And they cause farmers all around the world to produce more of the diverted or diminished crops. Where farmers plant more cropland, and which kinds of additional lands they plant, will determine the magnitude of greenhouse gas emissions from land use change.

To estimate these effects for corn-based ethanol, our analysis started with an international agricultural model by economists with the Center for Agricultural and Rural Development at Iowa State University. This model calculates how diversions of ethanol in the United States cause U.S. farmers to switch crops and divert corn to ethanol, calculates the value of an important ethanol by-product for livestock feed (which replaces some of the corn and therefore does not encourage new land conversion), and then calculates how farmers around the world respond both by shifting crops and planting new lands. For a specific rise in corn ethanol, this analysis predicted how much consumers would reduce demands, and how much additional cropland would come into prediction in major crop-producing countries (or in some cases, groups of countries). The model allows all these adjustments to react to each other. The model also recognizes that different countries achieve different crop yields, and as a whole, when crops are replaced abroad instead of produced in the United States, more land is needed.

The next question is what types of land will be converted to supply the new cropland. We used data collected at Woods Hole Research Center from a variety of sources estimating the proportion of newly converted cropland in different world regions that come out of different types of forest or grassland. For each of these forest or grassland types, we estimated the level of greenhouse gases released by conversion to cropland.

This analysis produces a total amount of greenhouse gas emissions from land use change for a given expansion of corn ethanol. It can be turned into a level of emissions from land use change per unit of fuel or per mile driven with that fuel. To analyze impacts on greenhouse gases, you must start by assuming some specific increase in ethanol. Ultimately, however, you use that to calculate a rate of greenhouse gas emissions per liter. The size of the increase may influence the rate, but probably only modestly.

Other lifecycle analyses tend to calculate greenhouse gas emissions as a level of emissions per mile or kilometer driven, or as a level of emissions per energy content of fuel. For all other parts of the lifecycle analyses, we used a model developed at Argonne Laboratories in Illinois called the GREET model, which is probably the most commonly used analysis. We amortized our analysis of land use change over 30 years and factored those emissions into the GREET model. The result is that switching from gasoline to corn ethanol doubles greenhouse gas emissions for every mile driven, instead of decreasing those emissions by 20 percent as predicted by GREET alone. Viewed another way, corn ethanol will eventually payback the carbon debt—the initial increase in emissions from land use change—but only after 167 years, which means it will increase global warming gases until then.

What about second-generation biofuels and those from oil seeds?

Previous lifecycle analyses have tended to show corn ethanol as having smaller benefits than other biofuels, so what does our analysis suggest about them—particularly the much vaunted "second-generation" biofuels that mostly refer to various forms of cellulose? Unfortunately, any biofuel that requires dedicated land will also cause land use change and its greenhouse gas emissions. Cellulose might come from a variety of sources, but if it uses productive land, it will still have large land use change costs. The calculations above make it easy to calculate the total effect on greenhouse gas emissions from ethanol made from switchgrass if grown on average U.S. corn land. Although switchgrass is better than corn ethanol, it would still increase emissions compared to gasoline over 30 years by 50 percent.

Ralph Heimlich and I have also separately calculated the emissions from land use change of biodiesel made from soybeans.[7] Excluding land use change, soybean biodiesel has fewer emissions than corn because growing soybeans uses less fertilizer and refining it into biodiesel uses less energy. But yields are also much smaller, and some of the land use change is likely to occur on the peat soils of southeast Asia where palm oil is produced, which triggers large emissions. Our best estimate is that soy biodiesel increases greenhouse gas emissions by 158 percent over 30 years.[8]

There are a broad range of possible biofuel sources, and the calculations will vary from one biofuel to another, but emissions from land use change will be significant for any biofuels that use productive land.

The significance of uncertainties

There are inherent uncertainties with this kind of analysis because it requires the basic assumption that future behavior will largely mimic the past and because government policies can influence which kinds of lands are converted to replace diverted crops. How confident can we be in the final result?

We believe the basic result is robust for a number of reasons. First, we reanalyzed the numbers using a large number of favorable assumptions for corn ethanol and still could not generate greenhouse gas benefits over 30 years. In fact, even if corn ethanol caused no emissions other than those from land use change, it would still increase greenhouse gases modestly over 30 years.

Second, there is a basic intuitive logic to the result. Forests and grasslands have typically been removing carbon from the atmosphere and storing it for years. Converting them to cropland for biofuels tends to release large quantities of this carbon. By contrast, ignoring land use change, each hectare of land used for biofuels in a year generates only a modest greenhouse gas benefit.

For example, a hectare of corn produces a greenhouse gas savings of roughly 1.8 metric tons per hectare, and a hectare of switchgrass for ethanol around 8.6 metric tons but a hectare of forest conversion will release between 600 to more than 1000 metric tons of greenhouse gases, and the conversion of a hectare of grassland can release 300 metric tons. For this reason, if even a significant fraction of each hectare of biofuels is replaced out of these kinds of habitats, the greenhouse gas emissions are likely to exceed the benefits of biofuels for decades.

Third, although the precise location and type of land conversion

[7] T. Searchinger and R. Heimlich, "Estimating Greenhouse Gas Emissions from Soy-Based U.S. Biodiesel When Factoring in Emissions from Land Use Change," presented at workshop on Biofuel Lifecycle Analysis sponsored by the U.S. Department of Agriculture and Farm Foundation, Miami Beach, Florida January 29, 2008.

[8] This calculation uses simpler agricultural modeling than that for the corn ethanol analysis. Most significantly, it limits where replacement vegetable oil can come from to the major exporting countries, which is a reasonable but rougher approximation. This analysis also conservatively attributes only 19 percent of the expansion of soybeans to biodiesel – the percentage of the soybean by weight that goes into oil – because the remainder of the soybeans contribute new food. And this analysis assumes that 40 percent of the soybean oil is either not replaced because of higher prices or because higher vegetable oil price cause producers to generate higher yields on existing croplands.

could vary, the emissions from most lands remain high. Forests have more carbon in plants, but grasslands—particularly those wet enough to provide productive land for crops—tend to have more carbon in soils. Young forests release less carbon when immediately converted. But young forests would also tend to sequester a great deal of carbon over 30 years or more as they grow, unlike mature forests that have typically achieved a rough carbon balance already.

Finally, as a whole, we consider our estimates more likely to be low than high. The biggest factor that could make our estimate too high is a possible underestimate of increases in yields that could be spurred by higher crop prices due to ethanol. Higher prices will encourage farmers to use more fertilizer, irrigation, and drainage to increase yields. They will also push farmers into more marginal lands. We assumed that yields would continue to increase as they have in the past but that these additional effects of biofuels would cancel each other out. The actual effect of higher prices on yields is unknown, and any estimate faces daunting methodological problems. Our estimate could be low; however, even if half of all replacement grain came from further increases in yields, our basic result for crop-based ethanols would not differ.

> "Higher prices will encourage farmers to use more fertilizer, irrigation, and drainage to increase yields. They will also push farmers into more marginal lands."

We also used many assumptions that tended to underestimate emissions. For example, around half of our predicted new cropland would come from plowing up grassland. Nearly all the world's grasslands are grazed and contribute to meat production. Some of the world's forest conversion is occurring to expand grasslands for meat. We assumed that the loss of this grass forage would not trigger any additional conversion (essentially because no existing models provide a good basis for estimating that expansion). In reality, this effect could lead to significant additional forest loss.

Our analysis also assumed no conversion of wetlands except in Southeast Asia. Many wetlands have deep organic soils, and when drained for agriculture (a huge source of cropland in much of the world), the soils tend to decompose rapidly giving up huge volumes of carbon. Conversion of even some wetlands could greatly increase the greenhouse gases.

Finally, the engineering parts of our analysis (the part taken from GREET) assume certain rates at which nitrogen fertilizer is converted to nitrous oxide—a potent greenhouse gas. Serious questions have now been raised about whether those rates are much higher in reality, which would significantly increase the emissions attributable to agriculture and crop-based biofuels.[9]

Impacts on habitat

Land use change not only contributes greenhouse gases, it also destroys habitat. Much of recent agricultural expansion has taken place in Brazil, converting a kind of forest and savannah complex called the Cerrado. The Cerrado is remarkably biologically diverse, with 10,000 native plants of which 44 percent occur nowhere else. Other valuable habitats undergoing conversion include the Amazon rainforest and the rainforests of Southeast Asia. Biofuels will cause the conversion of more of these habitats.

Which biofuels avoid emissions from land use change or might otherwise remain most beneficial?

Only biofuels that use a feedstock that is likely to lead to changes in land use trigger emissions from land use change. Most significantly, biofuels that use waste products will not trigger land use change. Potentially significant sources include municipal and industrial wastes or agricultural wastes, such as the non-grain "stover" portions of corn, or rice straw. An analysis by the U.S. Department of Agriculture and the U.S. Department of Energy has identified large potential sources of such waste products.[10]

Using agricultural wastes, however, needs to occur with care. Many of those crop residues are left on the soil in the winter and eventually plowed into it, limiting soil erosion and contributing organic matter and nutrients. Their removal and use for biofuels has potential carbon costs as well as other environmental effects. Forest wastes could also contribute to biofuels if they are true waste products. Many wastes from forests; however, have some use and their replacement would trigger at least some emissions from land use change.

Our analysis also does not directly calculate impacts of biomass from forestry. Cutting down forests and directly using them for biofuels would obviously cause the release of the carbon in trees

[9] P.J. Crutzen, A.R. Mosier, K.A. Smith, and W. Winiwarter, "N2O Release from Ago-Biofuel Production Negates Global Warming Reduction by Replacing Fossil Fuels," Atmos. Chem. Phys. Discuss 7:11191-11205 (2007).
[10] R.D. Perlack et al., "Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," (Tech. Rep. ORNL/TM 2006/66, Oak Ridge National Laboratory, Oak Ridge, TN, 2005).

and roots, and possibly some of the carbon in soils. Re-growing those forests would recoup some of that carbon over 30 years. But much of the carbon in roots will continue to decay after trees are harvested, perhaps 30 percent or more of the carbon in forests. And most of the forests contemplated for this kind of use will be re-growing forests that would continue to sequester carbon over the next decades anyway. Alternatively, if forests are planted on grassland, the lost forage for livestock must be addressed. A proper analysis of forest biomass must fully account for the opportunity costs of maintaining existing forest or grassland uses.

In theory, it might also be possible to produce biofuels on marginal, often abandoned, agricultural land. For this purpose, marginal land does not just mean marginal from an agricultural standpoint, but marginal from any productive standpoint: whether of crops, grass or forest. Use of any productive land for biofuels sacrifices at least some alternative carbon benefit that needs to be factored into a greenhouse gas analysis. In addition, most analyses estimate that agricultural land will need to expand to feed a growing world population, including many people eating better because of rising incomes in at least some locations. It is likely that many "marginal lands" productive enough to produce biofuels well could also supply some of that needed food, and if not available, will require food production to expand into productive forest and grassland.

"Sugarcane, under careful conditions, might also be a source of biofuels that provides greenhouse benefits."

Sugarcane, under careful conditions, might also be a source of biofuels that provides greenhouse benefits. In Brazil, sugarcane is grown with remarkable productivity. Already, most of the sugarcane plant is used for energy with considerable efficiency, and that efficiency is likely to continue to grow. Sugarcane also contributes to electricity production in a way that probably has greater greenhouse gas benefits than using sugarcane for electric fuel because it offsets alternative ways of making electricity that emit more greenhouse gases.

However, sugarcane is part of the overall agricultural expansion in Brazil that continues to consume more of the Amazon and Cerrado, whether sugarcane itself directly replaces those habitats or pushes into soybean fields and grasslands that themselves then expand. (Brazilians, of course, defend their moral right to use more of their land for agriculture just like people in the northern hemisphere, with some justification, but the need to curb that expansion to solve climate change remains critical.)

For sugarcane ethanol to produce true greenhouse benefits, Brazil has to control its overall agricultural expansion, and displaced crops or forage from sugarcane expansion must be made up in additional ways. Because of sugarcane's extraordinary productivity, I believe there is the potential for a worldwide deal with Brazil—perhaps in connection with a new climate change treaty—that incorporates increased consumption of sugarcane ethanol. To reflect full environmental effects, it should also include a more coordinated national effort to save more coordinated corridors of Cerrado—most of the Cerrado that remains is broken up into little chunks. Achieving such a deal will be a political and technical challenge, but worth the effort.

What if we all became vegetarians or found other ways to reduce the need for cropland?

Because the continuing need to feed people triggers the land use change, people often ask if land use change could be avoided by finding other ways to reduce food consumption, for example, by a worldwide change in diet. Much crop production supports meat consumption, so vegetarianism as a whole is likely to reduce overall crop demands. Others more generally claim that we do not have to choose between food and fuel; we can produce more of both by making further efforts to increase crop yields.

Both changed diets and improved yields would reduce agricultural land use change, but they do not by themselves change the answer to the question: What is the net effect of biofuels? They would reduce greenhouse gases, but those reductions are independent of biofuels. Each hectare of biofuels still leads to the loss of some fraction of a hectare of forest or grassland. It is not legitimate to attribute greenhouse gas savings to biofuels for actions that would reduce greenhouse gases anyway.

What about surplus cropland?

Some people have heard about surplus cropland for so many years that they find it hard to believe biofuels could not use millions of hectares of cropland otherwise lying around doing nothing. There are a number of responses.

First, the reality is that cropland and grazing land have been expanding on a worldwide basis. Until the recent biofuel boom, they have expanded little in North America and actually declined in Europe, but they have expanded greatly in Latin America and to a lesser extent in Asia and Africa. Cropland is expanding because it is increasingly cheaper to produce food in these new locations, a result of improved technology and infrastructure. Higher crop prices due to biofuels will accelerate that expansion.

Second, what people think of as surplus croplands are largely the croplands that are not used when prices are low. Crop prices fluctuate. When prices are high, additional lands are planted. When prices are low, fewer lands are planted. There is always a set of lands that come in and out of crop production depending on prices. Biofuels shift the entire "demand curve" out, increasing prices overall and requiring more land, but there will still be price fluctuations, and the amount of cropland planted each year will still reflect those variations in price.

"A kind of reverse Murphy's Law in effect creeps into biofuel papers; if anything can go right it will."

Third, to the extent croplands become truly surplus over a longer term in certain regions, those lands tend to revert to forest or grassland. That has happened over time in much of the United States. When lands revert, they start sequestering carbon in trees, grasses and soils, and that will often exceed the value of using the same lands for biofuels. Foregoing these carbon benefits because of biofuels is still a carbon cost of land use change that must be factored into the overall accounting of biofuels. From the standpoint of greenhouse gases, there are no surplus, productive lands.

Reverse murphy's law versus the market

To boost the prospects of biofuels, some analysts try to imagine perfect sets of conditions in which biofuels are not only produced in the best possible way, but farmers who replace diverted crops also choose the most beneficial methods of doing so. A kind of reverse Murphy's Law in effect creeps into biofuel papers; if anything can go right it will. Where and how producers replace crops diverted to biofuels will primarily reflect market conditions: production will generally occur in the cheapest places it can occur given other constraints. A proper analysis has to focus on these market effects, which will generally not be the most desirable from a greenhouse gas perspective.

Impacts on food consumption

Biofuels increase demands for food products or cropland, increase crop prices and therefore somewhat reduce demands for food. Because these effects work their way through so many different food products, which are not directly comparable, it is not possible to provide one percentage. Our analysis indicated, that roughly ten percent of the feed grains for meat diverted to ethanol would not be replaced because of reduced meat consumption, and around half of that reduction for dairy products. There are also indirect effects, for example on vegetable oil prices even from corn-ethanol, and biodiesel's main effect is on vegetable oils. These reductions in food create greenhouse gas benefits that we mostly (but not completely) calculate in our analysis. Since around half of these reductions occur in the developing world, where people are most likely to suffer inadequate nutrition, the impacts are not desirable.

Impacts on the poor from both increasing biofuels and land conversion worldwide

Expanding cropland is a relatively cheap, quick way of replacing food diverted to biofuels. If world policies simultaneously expanded demand for biofuels, but prohibited or discouraged agricultural expansion to replace the food, the costs of crops would rise even more than we calculated. As prices rise, farmers would invest in increasingly expensive ways of boosting yields on existing cropland—for example, with increased fertilizer, irrigation and drainage, which also tend to have significant environmental effects—but people would also reduce their food consumption even more. Less land use change would occur, generating greenhouse gas benefits, but much of those benefits would in effect result from reduced food consumption, perhaps half of which would come from hundreds of millions of the world's poorest people.

What about environmental standards or certification programs that prohibit direct use of new croplands from forest or grassland and what about standards-based on greenhouse gas reductions

The EU directive discussed above and various certification programs have been examining environmental standards that bar biofuels produced on newly converted cropland from forest or grassland. For the reasons already discussed, such policies would not work because biofuels would use existing crops and croplands and conversion would continue to replace those crops.

U.S. law and California's Low Carbon Fuel Standard Initiative also require agencies to calculate greenhouse gas impacts of different biofuels and to incorporate indirect land use change. Where and how crops diverted to biofuels are replaced is largely outside the control of individual producers. For this reason, the only viable method of calculating land use change must attribute to each type of biofuel a level of emissions from land use change calculated by the agency. Of course, getting agreement on these numbers will be hard. Although the general direction of our calculations seems robust, people could legitimately differ over details that have significant effect for those biofuels at the margin. Any proper public policy analysis of biofuels; however, should also take account of the other environmental effects from land use change and increased use of agricultural inputs. It should also account for the full opportunity cost of using land to produce biofuels instead of other alternatives, which might include other carbon-enhancing efforts on lands, or using land to meet growing food demands.

The larger global picture

The global picture provides another angle to view the biofuel challenge. Although fossil fuel use contributes around 80 percent of the world's increased carbon dioxide, land use changes, such as deforestation, contribute around 20 percent. Most analyses estimate the need for continued deforestation to meet growing food demands for more people, many of whom will eat better.[11] Meanwhile, the Intergovernmental Panel on Climate Change (IPCC) analysis of economically efficient methods for reducing greenhouse gases assigns a prominent role to reduced deforestation or even reforestation. Our analysis indicates that dedicating productive land to biofuels would reduce the fossil fuel problem but only at the expense of making the land use change and deforestation problem worse. In rare cases, would the net effect be good.

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In 1992, he received a National Wetlands Protection Award in 1992 from the Environmental Protection Agency and the Environmental Law Institute. He has authored numerous briefs in the Supreme Court on issues ranging from takings to age discrimination.

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[11] J. Bruisnsma, Ed., World Agriculture: Toward 2015/30, an FAO Perspective (Food and Agricultural Organization of the UN, Rome and London, 2003).