Letter to *Science*
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The article by Searchinger et al. in *Sciencexpress* ("Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change," February 7, 2008) provides a timely discussion of fuel ethanol's effects on greenhouse gas (GHG) emissions when taking into account GHG emissions from potential land use changes induced by ethanol production.

Land use change issues associated with biofuels were explored in life-cycle analyses beginning in early 1990s (Delucchi 1991). In general, the land use changes that occur as a result of biofuel production can be separated into two categories: direct and indirect. Direct land use changes involve direct displacement of land for farming of the feedstocks needed for biofuel production. Indirect land use changes are those made to accommodate farming of food commodities in other places in order to maintain the global food supply and demand balance.

Searchinger et al. used the GREET model developed by one of us at Argonne National Laboratory in their study (see Wang 1999). They correctly stated that the GREET model includes GHG emissions from direct land use changes associated with corn ethanol production; the emissions estimates in GREET are based on land use changes modeled by the U.S. Department of Agriculture (USDA) in 1999 for an annual production of 4 billion gallons of corn ethanol in the United States by 2010. Needless to say, the ethanol production level simulated by USDA in 1999 has been far exceeded by actual ethanol production — about 6 billion gallons in 2007 (Renewable Fuels Association 2008). Thus, the resultant GHG emissions from land use changes provided in the current GREET version need to be updated. Argonne, and several other organizations, recently began to address both direct and indirect land use changes associated with future, much-expanded U.S. biofuel production. Such an effort requires expansion and use of general equilibrium models at the global scale.

Many critical factors determine GHG emission outcomes of land use changes. First, we need to clearly define a baseline for global food supply and demand and cropland availability *without* the U.S. biofuel program. It is not clear to us what baseline Searchinger et al. defined in their modeling study.

Searchinger et al. modeled a case in which U.S. corn ethanol production increased from 15 billion gallons a year to 30 billion gallons a year by 2015. However, in the 2007 Energy Independence and Security Act (EISA), Congress established an annual corn ethanol production

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cap of 15 billion gallons by 2015. Congress established the cap — based on its awareness of the resource limitations for corn ethanol production — to help prevent dramatic land use changes. Thus, Searchinger et al. examined a corn ethanol production case that is not directly relevant to U.S. corn ethanol production in the next seven years.

Corn yield per acre is a key factor in determining the total amount of land needed for a given level of corn ethanol production. It is worth noting that U.S. corn yield *per acre* has steadily increased — nearly 800% in the past 100 years (Perlack et al. 2005). Between 1980 (the beginning of the U.S. corn ethanol program) and 2006, per-acre corn yield in the United States has increased at an annual rate of 1.6% (Wang et al. 2007). Seed companies are developing better corn seeds that resist drought and pests and use nitrogen more efficiently. Corn yield could increase at an annual rate of 2% between now and 2020 and beyond (Korves 2007). The statement "We assume that these positive and negative effects on yield balance each other out although we test an alternative scenario in our sensitivity analysis" (p.6 of the supporting online material) may lead readers to interpret that Searchinger et al. used a constant corn yield in their simulations. After direct communications with us, the authors clarified that the historical trend of corn yield growth in the U.S. was assumed in their study.

Searchinger et al. also assumed that distillers' grains and solubles (DGS) from corn ethanol plants would displace corn on a pound-for-pound basis. The one-to-one displacement ratio between DGS and corn fails to recognize that the protein content of DGS is much higher than that of corn (28% vs. 9%). The actual displacement value of DGS is estimated to be at least 23% higher than that assumed by Searchinger et al. (Klopfenstein et al. 2008).

Searchinger et al. estimated that U.S. corn ethanol production (between 15 billion and 30 billion gallons) would result in an additional 10.8 million hectares of crop land worldwide: 2.8 million hectares in Brazil, 2.3 million hectares in China and India, and 2.2 million hectares in the United States, and the remaining hectares in other countries. The researchers maintain that with their simulated corn ethanol production scale, the United States will experience export reductions of 62% for corn, 31% for wheat, 28% for soybeans, 18% for pork, and 12% for chicken.

Historically, U.S. corn exports have fluctuated around the 2-billion-bushel-a-year level since 1980. In 2007, when U.S. corn ethanol production increased dramatically, its corn exports increased to 2.45 billion bushels — a 14% increase from the 2006 level. This increase was accompanied by a significant increase in DGS exports by the United States — from 0.6 million metric tons in 1997 to 3 million metric tons in 2007. Some researchers anticipate that with corn ethanol production of around 15 billion gallons by 2015, U.S. will be able to maintain its corn export at the present level or at a moderately increased level (Korves, 2007). One of the factors that cause dramatic U.S. export reductions in agricultural commodities in Searchinger et al. study is the arbitrarily high corn ethanol production of 30 billion gallons by 2016.

Searchinger et al. had to decide what land use changes would be needed in Brazil, the United States, China, and India to meet their simulated requirement for 10.8 million hectares of new crop land. With no data or modeling, Searchinger et al. used the historical land use changes that occurred in the 1990s in individual countries to predict future land use changes in those countries (2015 and beyond). This assumption is seriously flawed by predicting deforestation in the Amazon and conversion of grassland into crop land in China, India, and the United States. The

fact is, deforestation rates have already declined through legislation in Brazil and elsewhere. In China, contrary to the Searchinger et al. assumptions, efforts have been made in the past ten years to convert marginal crop land into grassland and forest land in order to prevent soil erosion and other environmental problems.

In estimating the GHG emissions payback period for corn ethanol, Searchinger et al. relied on the 20% reduction in GHG emissions that is provided in the GREET model for the current ethanol industry. Future corn ethanol plants could improve their energy efficiency by avoiding DGS drying (in some ethanol plants) or switching to energy sources other than natural gas or coal, either of which would result in greater GHG emissions reductions for corn ethanol (Wang et al. 2007). Searchinger et al. failed to address this potential for increased efficiency in ethanol production.

In one of the sensitivity cases, Searchinger et al. examined cellulosic ethanol production from switchgrass grown on land converted from corn farms. Cellulosic biomass feedstocks for ethanol production could come from a variety of sources. Oak Ridge National Laboratory completed an extensive assessment of biomass feedstock availability for biofuel production (Perlack et al. 2005). With no conversion of crop land in the United States, the study concludes that more than 1 billion tons of biomass resources are available each year from forest growth and by-products, crop residues, and perennial energy crops on marginal land. In fact, in the same issue of *Sciencexpress* as the Searchinger et al. study is published, Fargione et al. (2008) show beneficial GHG results for cellulosic ethanol.

On the basis of our own analyses, production of corn-based ethanol in the United States so far results in moderate GHG emissions reductions. There has also been no indication that U.S. corn ethanol production has so far caused indirect land use changes in other countries because U.S. corn exports have been maintained at about 2 billion bushels a year and because U.S. DGS exports have steadily increased in the past ten years. U.S. corn ethanol production is expected to expand rapidly over the next few years — to 15 billion gallons a year by 2015. It remains to be seen whether and how much direct and indirect land use changes will occur as a result of U.S. corn ethanol production.

The Searchinger et al. study demonstrated that indirect land use changes are much more difficult to model than direct land use changes. To do so adequately, researchers must use general equilibrium models that take into account the supply and demand of agricultural commodities, land use patterns, and land availability (all at the global scale), among many other factors. Efforts have only recently begun to address both direct and indirect land use changes (see Birur et al. 2007). At this time, it is not clear what land use changes could occur globally as a result of U.S. corn ethanol production. While scientific assessment of land use change issues is urgently needed in order to design policies that prevent unintended consequences from biofuel production, conclusions regarding the GHG emissions effects of biofuels based on speculative, limited land use change modeling may misguide biofuel policy development.

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