LETTERS

edited by Jennifer Sills

Biofuels: Waste Not Want Not

THE REPORTS "LAND CLEARING AND THE BIOFUEL CARBON DEBT" (J. FARGIONE *ET AL.*, 29 February, p. 1235) and "Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change" (T. Searchinger *et al.*, 29 February, p. 1238) underscore the sobering reality that producing biofuels from edible crops will drive agricultural expansion, which could negate greenhouse gas (GHG) savings brought about by substituting biofuels for gasoline or result in net GHG emissions.

Other recent studies also highlight potential environmental impacts of producing food crop–based biofuels (*1–4*). Nevertheless, many scientists remain optimistic that with technological advancements (such as lignocellulose-to-ethanol conversion), there are real opportunities in generating biofuel energy from waste biomass (*3*).

Urban trees. Horticultural waste biomass from Singapore's planted trees could help offset the nation's fossil fuel consumption.

Singapore is a small (~700 km^2) tropical island in Southeast Asia with few natural resources. It relies heavily on imports of fossil fuels to meet its energy demands. This island nation ranks 20th in the world in terms of per capita carbon dioxide emissions (*5*), and it serves as an ideal case study to demonstrate the potential of using cellulosic wastes to supply a city's energy demands and reduce its GHG emissions. Singapore's urban areas are home to about 1 million planted trees, which produce 50,000 to 156,000 tons of horticultural waste biomass (tree trunks, twigs, and leaves) each year (*6*). A recent study estimates that each ton of woody biomass feedstock can produce 288 to 371 liters of cellulosic ethanol (*7*). This translates to between 14 and 58 million liters of ethanol fuel that can potentially be produced annually from Singapore's horticultural wastes, which can displace 1.6 to 6.5% of the city's transport gasoline demand (888 million liters) (*8*). Furthermore, recent studies estimate that use of cellulosic ethanol can reduce GHG emissions by 70 to 90% compared with conventional gasoline (*9*).

Our analysis suggests that biofuel produced from horticultural wastes can offset part of a city's energy needs. To realize the potential of biofuels as a petroleum alternative, we need to both expedite the development of new biofuel technologies and diversify the portfolio of biofuel feedstocks.

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Biofuels: Too Soon to Give Up

BIOFUELS ARE ESSENTIAL TO REDUCING OUR reliance on foreign oil and reducing greenhouse gas emissions. The recent Report by J. Fargione *et al*. ("Land clearing and the biofuel carbon debt," 29 February, p. 1235) claims that we need to be careful to avoid unintended consequences of biofuels. The accompanying Report by T. Searchinger *et al*. ("Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change," 29 February, p. 1238) adds that increased use of biofuels will actually increase carbon dioxide emissions because of deforestation and a sudden and major shift in land use.

Although there has been substantial rebuttal to the assumptions in the two Reports (*1*, *2*), these studies do highlight the need for a comprehensive analysis of the effects of biofuel production. Fortunately, new efforts are under way to address this issue. The Intergovernmental Panel on Climate Change will produce a comprehensive Special Report on the GHG Mitigation Potential of Renewable Energy. Also, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy and its national labs are committed to sustainability and have been addressing these issues, including a comprehensive life-cycle analysis of large-volume production of biofuel by the National Renewable Energy Laboratory, which will be vetted by leading scientists in the United States and around the world.

There is significant potential for second-generation biofuels to reduce carbon emissions when compared to first-generation biofuels

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technologies. However, the challenge to our nation in reducing our dependence on foreign oil is too great to abandon first-generation technology for fear of unintended consequences; instead, we must learn from comprehensive life-cycle analyses how to avoid those consequences as the biofuels market evolves.

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Biofuels: Think Outside the Cornfield

THE REPORT BY T. SEARCHINGER *ET AL*. ("Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change," 29 February, p. 1238) adds to the growing concerns regarding the inadequacies and risks associated with corn biofuels [e.g., (*1*)]. The study correctly points out, as does the Report by J. Fargione *et al*. ("Land clearing and the biofuel carbon debt," 29 February, p. 1235), that the conversion of many types of natural landscapes to grow corn for feedstock is likely to create substantial carbon emissions that will exacerbate global warming. Because of the potential problems with corn-based biofuels, it is useful to consider other alternatives.

One example is switchgrass, which grows well on marginal lands that are not well suited to corn or many other grains (*2*). Switchgrass would have another advantage: It is a self-seeding crop, which means farmers would not have to plant and reseed after harvesting.

Another alternative biofuel feedstock is wood from sustainably managed forests, which are common in much of the world today. These forests, managed for growth and renewability, are an increasing source of traditional industrial wood (*3*). As with grasses, trees can grow readily on land unsuitable for corn and grains. Furthermore, the wood is drawn from the incremental growth of a forest, thereby leaving the basic forest system and its carbon intact. Wood feedstock could be drawn from existing sources or from additional forests planted on marginal agricultural land without compromising the basic sustainable forest system, releasing substantial volumes of carbon, or utilizing high-quality crop lands (*4*). Moreover, infrastructure systems are currently in place, allowing wood to be harvested and transported.

Unlike corn and most grains, studies show that biofuels from grasses and wood have large net GHG gas savings. Indeed, grasses and trees enhance the ability of land to capture carbon through biomass and soils (*5*).

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Biofuels: Putting Current Practices in Perspective

WE HAVE THREE COMMENTS REGARDING THE Report on the carbon debt of biofuels by J. Fargione *et al.* ("Land clearing and the biofuel carbon debt," 29 February, p. 1235).

First, the argument that converting land from permanent vegetation to biomass has detrimental environmental effects has to be tempered by the fact that, globally, relatively little land is used for biofuels. Biofuels currently cover about 10 million hectares (*1*) out of a total cropping land area of 1.5 billion hectares and a total pasture area of 4.5 billion hectares. In addition, the total greenhouse gas debt—composed of CO_2, CH_4, and N_2O emissions—caused by biofuel primary production is small compared with the debt associated with the 26% of the ice-free global terrestrial surface given over to animal grazing and the 33% of arable land used to produce animal feed. More than 60% of global wheat, barley, and maize and more than 90% of soybean production is used as animal feed (*2*).

Second, land clearance combined with existing agricultural practice and fuel conversion technologies is the worst possible scenario for biomass. Growing crops for energy requires new thinking about crops and agricultural systems. The food crop "ideotype" (*3*)—developed to have a short stem, small erect leaves, and high C and N harvest indices—was the model plant of the green food revolution of the 1960s. Biomass for energy, harvested for its carbon and not for its nitrogen (protein) content, requires a different ideotype. A long growing season is necessary, as is large leaf size to compete against weeds. Fungal disease resistance should be multigenic, and mixed cultivar plantings should be encouraged. Perenniality rather than an annual habit would also confer advantages in reducing crop establishment energy costs and emissions of CH_3 and NO_2. Biomass crops intended for fermentation require high concentrations of low molecular weight carbohydrates, in order to reduce energy inputs. Low N fertilizer inputs and high N use efficiency are desirable biomass properties for low emissions of N_2O (*4*), the major greenhouse gas of cereal food crops.

Third, biomass energy production requires plantings, rotations, and management that generate ecosystem services such as carbon sequestration, pollination, and biodiversity conservation as well as primary food production (*5*).

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Response

PORTER *ET AL.* CONTEND THAT THE TOTAL LAND area currently devoted to biofuel production is insufficient for the CO_2 released by land use change to be meaningful on a global scale. The focus of our paper was not on the current

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magnitude of global greenhouse gas emissions from land clearing for biofuels, but on what would happen to CO_2 release if biofuel production were to expand greatly by using newly cleared lands. The amount of land dedicated to biofuel production is increasing rapidly (*1*, *2*). Current biofuel land clearing emissions may not yet be a major contributor to global agricultural GHG emissions, but that is poor justification for letting them become so. Similarly, we agree that crop production for animal feed already contributes substantially to GHG emissions, but we do not see this as grounds to develop biofuels that do the same.

Porter *et al*. then suggest that biofuel crops should be improved to increase yield and therefore the fossil fuel offset per hectare. We agree that perennial crops will be essential for the future of sustainable biofuels. Indeed, this has been a central focus of the emerging biofuel industry for decades (*3*–*6*) and was a main point of our Report. However, opportunities for biofuel and bioenergy production extend beyond dedicated biofuel crops to include waste biomass and algae. The agronomic approaches suggested by Porter *et al*. must still account for possible impact on land clearing and should be compared against alternative methods of production that do not cause land clearing.

Finally, Porter *et al*. advocate consideration of ecosystem services as a part of the biomass cropping system. We concur. This echoes similar calls we have made for optimizing the value of ecosystem services that can be provided by well-designed food and biomass cropping systems (*4*, *7*–*9*).

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CORRECTIONS AND CLARIFICATIONS

Editors' Choice: "Leave it to Mimi" (16 May, p. 850). The first author of the *PLoS Biology* study was Zauberman, not Zuberman.

News Focus: "The roots of morality" by G. Miller (9 May, p. 734). Jordan Grafman's affiliation was reported incorrectly. He is at the National Institute of Neurological Disorders and Stroke.

Letters to the Editor

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