Carbon Mitigation by Biofuels: How benign are Biofuels?

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Introduction

Several phenomena such as sea level rise, significant damage to agricultural crops, and increased intensity and frequency of extreme weather events are often observed and considered to be due to global warming. The further effects of global warming on the environment and on human life may extend to more events, including outbreak of a highly contagious disease, loss of forests, and depletion of the ozone layer, while the extent and likelihood of these consequences are a matter of considerable controversy.

A few scientists in the 19th century speculated on the mechanism of the greenhouse effect from carbon dioxide (CO_2) and other gases in the atmosphere, but then it was not discussed widely. However, the scientific consensus today identifies greenhouse gases (GHGs) as the primary cause of the recent warming.

Merkel advocated 'sustainable development' to reconcile environmental protection with development as the key aim for the 21st century ['The Role of Science in Sustainable Development', *Science*, **281**, 336-337(1998)]. She emphasizes that science must play an important role in the pursuit of sustainable development in the following categories: energy use, closure of substance cycles, environmentally compatible mobility, and biotechnology. Even in the face of increasing awareness about environmental protection, the sustainable balance of the well-known links between 3 E's (economic growth, energy and environment) is exacerbated.

As an administrative approach, emission trading to control the amount of pollutants such as CO_2 and NO_x is put into shape on the government-to-government level in European Union, and also the Japanese government begins to consider the implementation of the trading system, which is expected to bring about developments or findings of improved technologies in future years.

At present choosing from among a host of strategies for mitigation of anthropogenic CO_2 emissions is not easy, but one strategy has received extensive attention, that is, the use of biofuels for transport, which makes up one of the most important bases of human activities. Because biofuels offer the possibility of producing energy without a net increase of CO_2 into the atmosphere, biofuels are, in theory, more carbon neutral and less likely to increase atmospheric concentrations of GHGs than fossil fuels. However, doubts have been raised as to whether this benefit can be achieved in practice; for examples, several papers in *Science* have stirred up controversies on how benign or green biofuels are.

Here, the author introduces the main points of arguments developed in these papers.

Discussion

Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass, D. Tilman, *et al*. *Science*, **314**, 1598-1600(2006)

Tilman, *et al*. performed an experiment on agriculturally degraded and abandoned nitrogen-poor sandy soil, and determined bioenergy production and ecosystem carbon sequestration in 152 plots, planted in 1994, containing various combinations of 1, 2, 4, 8, or 16 perennial herbaceous grassland species. Plots were unfertilized, irrigated only during establishment, and otherwise grown with low inputs. They conclude that LIHD biofuels are carbon negative because net ecosystem CO_2 sequestration (4.4 Mg hectare^{-1} year^{-1} of CO_2 in soil and roots) exceeds fossil CO_2 release during biofuel production (0.32 Mg hectare $^{-1}$ year $^{-1}$), and also LIHD biofuels can be produced on agriculturally degraded lands and thus need to neither displace food production nor cause loss of biodiversity via habitat destruction.

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Comment on 'Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass' M. P. Russelle, *et al*. *Science*, **316**, 1567b(2007)

Russelle *et al*. contend that Tilman *et al*.'s conclusions are not substantiated by the experimental protocol used, and Tilman *et al*. understated the management inputs required to establish prairies, extrapolated globally from site-specific results, and presented potentially misleading energy accounting.

Response to Comment on 'Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass' D. Tilman, *et al*. *Science*, **316**, 1567c (2007)

Tilman, *et al*. say that the nature of Russelle *et al*.'s comments suggests that research results well known in ecology may be less familiar to those outside the discipline, and refute Russelle, *et al*.'s technical concerns by a substantial body of research on prairie ecosystems and managed perennial grasslands.

Carbon Mitigation by Biofuels or by Saving and Restoring Forests? R. Righelato, *et al*. *Science*, **317**, 902(2007)

Righelato, *et al*. address two issues before the efficacy of biofuels can be assessed: the net reduction in fossil carbon emissions (avoided emissions) arising from use of agriculturally derived biofuels and the effect of alternative land-use strategies on carbon stores in the biosphere. They estimate avoided emissions to vary widely depending on crop, fuel type, and conversion technology used, and forestation of an equivalent area of land would sequester two to nine times more carbon over a 30-year period than the emissions avoided by the use of the biofuel.

Land Clearing and the Biofuel Carbon Debt, D. J. Fargione, *et al*. *Science*, **319**, 1235-1237 (2008)

Fargione, *et al*. admit that increasing energy use, climate change, and CO_2 emissions from fossil fuels make switching to low-carbon fuels a high priority, and biofuels are a potential low-carbon energy source. However, they have an emphasis on how biofuels to offer carbon savings are produced. They calculate that converting rainforests, peatlands, savannas, or grasslands to produce food crop-based biofuels in several countries creates a 'biofuel carbon debt' by releasing 17 to 420 times more CO_2 than the annual GHGs reductions that these biofuels would provide by displacing fossil fuels. In contrast, their results show that biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages.

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change, T. Searchinger, *et al*. *Science*, **319**, 1238-1240(2008)

Most prior studies have found that substituting biofuels for gasoline will reduce GHGs because biofuels sequester carbon through the growth of the feedstock. Searchinger, *et al*. point out that these analyses have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, they assign that corn-based ethanol, instead of producing a 20% GHG savings, nearly doubles greenhouse emissions over 30 years and increases GHGs for 167 years, and biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates and highlights the value of using waste products.

A New Vista of Biofuels

The above discussions suggest that not all biofuels are beneficial when their environmental impacts are assessed, and we have to acknowledge that the impacts of a particular energy source should be analyzed from all parts of the fuel life cycle. No energy source, not even solar and wind, is perfectly benign from an environmental perspective if each step in the energy life cycle is taken into consideration. Especially overconcentration in a particular energy source can cause some inevitable and serious impacts on environment. Biofuels should be viewed as a bridge to more energy-efficient technologies. Therefore, one of the preferable strategies to pave the way for biofuels, though considered as the second-best one, is to use natural and semi-natural grasslands without deforestation.