BIOFUELS:
LAND AND WATER CONCERNS

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Biofuels are fuels made from organic matter. They include liquid fuels such as ethanol, biodiesel, and methanol; gaseous fuels such as methane and carbon monoxide; and solid fuels such as biochar and the more traditional charcoal. Biofuels may have some environmental advantages over gasoline and diesel fuels, but they are more expensive to produce and cannot supply more than a small part of the world's total transportation energy needs. And because they compete with food crops and nature for land, water, and nutrients, expanding the use of biofuels could negatively affect human health and natural ecosystems.

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Elcock (2008) projects 12.9 billion gallons per day of water will be consumed in the manufacture of ethanol by 2030. This "increase accounts for roughly 60% of the total projected nationwide increase in water consumption over the 2005-2030 period, and it is more than double the amount of water projected to be consumed for industrial and commercial use in 2030 by the entire United States."

A 2009 study by Argonne National Laboratory estimated life-cycle water consumption for one gallon of four types of fuel: ethanol, gasoline from domestic conventional crude oil, gasoline from Saudi conventional crude oil, and gasoline from Canadian oil sands (Wu *et al*., 2009). For ethanol, they estimated an average consumption of 3.0 gallon of water/gallon of corn ethanol during the production process in a corn dry mill, a yield of 2.7 gallons of ethanol per bushel of corn, and the average consumptive use of irrigation water for corn farming in three U.S. Department of Agriculture Regions (5, 6, and 7) representing the vast majority of corn production in the United States. They found "total groundwater and surface water use for corn growing vary significantly across the three regions, producing 1 gallon of corn-based ethanol consumes a net of 10 to 17 gallon of freshwater when the corn is grown in Regions 5 and 6, as compared with 324 gallon when the corn is grown in Region 7." When these figures are adjusted to reflect the lower Btu/gallon of ethanol compared to gasoline (75,700 / 115,000, or .66), the amount of water consumed per gallon of gasoline equivalent ranges from 15.2 to 25.8 gallons in Regions 5 and 6 and 492 gallons in Region 7.

Wu *et al*. (2009) found the amount of water required to create a gallon of gasoline was dramatically less: 3.4-6.6 gallons of water to make one gallon of gasoline from U.S. conventional crude oil, 2.8-5.8 gallons to make one gallon of gasoline from Saudi conventional crude, and 2.6-6.2 gallons to make one gallon of gasoline from Canadian oil sands.

A literature review conducted by the International Council for Science (ICSU) found "the water requirements of biofuel-derived energy are 70 to 400 times larger than other energy sources such as fossil fuels, wind or solar. Roughly 45 billion cubic meters of irrigation water were used for biofuel production in [sic] 2007, or some 6 times more water than people drink globally" (ICSU, 2009). The authors also point out that "severe water pollution can result from runoff from agricultural fields and from waste produced during the production of biofuels," and that "the increase in corn [production] to support ethanol goals in the United States is predicted to increase nitrogen inputs to the Mississippi River by 37%."

Spiertz and Ewert (2009)[1] reviewed and discussed "the opportunities and limits of crops and resources for food, feed and biofuel production." The two researchers-one from the Netherlands and the other from Germany-determined "commercial biomass production will compete with food crops for arable land and scarce fresh water resources." And they say "the rapidly growing demand for food, feed and fuel will require a combination of further increases in crop yields (ca. 2% per annum) and a doubling or tripling of resource-use efficiencies, especially of nitrogen-use efficiency and water productivity in production systems with high external inputs." Thus, in the words of Spiertz and Ewert, biofuel production not only threatens "food security," but "water resources and biodiversity."

Purdue University's Thomas W. Hertel in his role as President of the Agricultural and Applied Economics Association offered similar remarks on the link between biofuel production and food security in his Presidential Address to the group (Hertel, 2011[2]). He stated that "the number of people which the world must feed is expected to increase by another 50% during the first half of this century," and "when coupled with significant nutritional improvements for the 2.1 billion people currently living on less than $2/day," he says "this translates into a very substantial rise in the demand for agricultural production." In addition, he writes the United Nations' Food and Agriculture Organization "estimates the increased demand at 70% of current production, with a figure nearer 100% in the developing countries (Bruinsma, 2009)."

"At the same time," as Hertel continues, "the growing use of biomass for energy generation has introduced an important new source of industrial demand in agricultural markets," as outlined by the Energy Information Agency (2010) of the U.S. Department of Energy. And compounding matters further, he notes that water, which is a key factor in agricultural production, "is rapidly diminishing in availability in many parts of the world (McKinsey & Co., 2009)," while "many soils

1 http://www.co2science.org/articles/V14/N11/B1.php.
2 http://www.co2science.org/articles/V14/N44/EDIT.php.

are degrading (Lepers *et al*., 2005)." And, last but not least, Hertel draws attention to the "global economic effects of changes in crops, pasture, and forests due to changing climate, carbon dioxide, and ozone," as described by Reilly *et al*. (2007) in a paper of the same title published in *Energy Policy*.

Hertel therefore asks the question: "Can we expect a perfect storm?" And in response, he cites the report of the Council for Agricultural Science and Technology (CAST), wherein Buchanan *et al*. (2010) write "numerous factors are converging to make 'the perfect storm' in global food and agriculture." He notes, for example, that CAST's "associated arguments are compelling: the global farm and food system will be asked to feed several billion more people, fuel millions of vehicles, supply power for electricity, supply fiber to the global textile industry and sequester carbon to mitigate climate change, all while yield growth is slowing, agricultural land is being degraded and/or removed for urban uses, and water is becoming increasingly scarce."

Can we expect a perfect storm?

The global farm and food system will be asked to feed several billion more people, fuel millions of vehicles, supply power for electricity, supply fiber to the global textile industry and sequester carbon to mitigate climate change, all while yield growth is slowing, agricultural land is being degraded and/or removed for urban uses, and water is becoming increasingly scarce.

Arima *et al*. (2011)[3] introduce their work by noting the "expansion of global demand for soy products and biofuel poses threats to food security and the environment," and "one environmental impact that has raised serious concerns is loss of Amazonian forest through indirect land use change (ILUC), whereby "agricultural activities displaced from one region are reconstituted in another one (Searchinger *et al*., 2008; Lapola *et al*., 2010)," which phenomenon, in their words, "has been hypothesized by many researchers," although they state it had not yet been measured statistically at the time, "owing to conceptual difficulties in linking distal land cover drivers to the point of impact." As their contribution to the subject, Arima *et al*. overcome this previous impasse "with a spatial regression model capable of linking the expansion of mechanized agriculture in settled agricultural areas to pasture conversion on distant, forest frontiers."

In applying their model to the period 2003-2008, the four scientists determined ILUC "is significant and of considerable magnitude." More specifically, they report "a 10% reduction of soy in old pasture areas would have decreased deforestation by as much as 40% in heavily

[3] http://www.co2science.org/articles/V15/N1/B1.php.

forested counties of the Brazilian Amazon." However, they say "the voluntary moratorium on primary forest conversions by Brazilian soy farmers has failed to stop the deforestation effects of expanding soy production." And they therefore contend that environmental policy in Brazil must pay attention to ILUC, although they say doing so can complicate that nation's efforts to achieve the goals of its United Nations-sponsored program for Reducing Emissions from Deforestation and Forest Degradation, which they state had "raised hopes for a new era of sustainable relations between coupled natural human systems in Amazonia," as discussed by Nepstad *et al*. (2009).

Concentrating in on the same region, in a thought-provoking article published in the *Annals of the Association of American Geographer*s (Walker, 2011[4]), Robert Walker of Michigan State University's Department of Geography writes that "although biofuel represents a renewable and 'green' energy," it has what he rightly calls "a downside," the potential problem being, as he describes it, "the impact of growing international biofuel demand on Amazonia." Therefore, focusing on Brazil, and "given the explosive growth of Brazilian agriculture, and notable effects on forests within its national borders," he sought to answer the question: "How will global demand for Brazil's land-based commodities, including biofuel, impact its tropical forest in the Amazon basin?"

In an attempt to provide an answer to this important question, Walker "describes recent agricultural expansion in Brazil and its emergent landscape of renewable energy." And using a form of rent theory, he goes on to frame "a concept of landscape cascade and shows how Brazil's expanding landscape of renewable energy is impacting forest areas at a great distance," after which he "considers recent projections of demand for Amazonian land out to 2020, given growth of Brazilian biofuel production and cattle herds." His projections indicate "more Amazonian land will be demanded than has been made available by Brazilian environmental policy," and he goes on to discuss the likely "discursive dismemberment of Amazonia and how this articulates with efforts by Brazilian politicians to increase the region's land supply," pointing out "agricultural intensification holds the key to meeting global demand without degrading the Amazonian forest, a landscape unique in the world for its ecological and cultural riches."

In a review paper discussing several environmental concerns about biofuel crop/plant production, including their impacts "on climate change, water use, and land use," Delucchi (2010)[5] writes "governments worldwide are promoting the development of biofuels, such as ethanol from corn, biodiesel from soybeans, and ethanol from wood or grass, in order to reduce dependency on oil imported from politically unstable regions of the world, spur agricultural development, and reduce the climate impact of fossil fuel combustion." In light of the magnitude of this huge endeavor, Delucchi reviewed what had been learned of the subject at that time. His analysis lead him to state "it is likely that biofuels produced from crops using conventional agricultural practices will not mitigate the impacts of climate change," but they will instead "exacerbate stresses on water supplies, water quality, and land use, compared with petroleum fuels." And to drive this point home, he quotes Phalan (2009) as stating "if risks and

4 http://www.co2science.org/articles/V15/N4/EDIT.php.
5 http://www.co2science.org/articles/V14/N4/B1.php.

uncertainties are inadequately assessed and managed, even the best biofuels have the potential to damage the poor, the climate and biodiversity." "To avoid these problems," Delucchi states "biofuel feedstocks will have to be grown on land that has no alternative commercial use and no potential alternative ecological benefits, in areas with ample rainfall or groundwater, and with little or no inputs of fertilizers, chemicals, and fossil fuels," adding "it is not clear that it can be done economically and sustainably at large scales."

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Beringer *et al*. (2011)[6] estimated "the global bioenergy potential from dedicated biomass plantations in the 21st century under a range of sustainability requirements to safeguard food production, biodiversity and terrestrial carbon storage," after which they explored the resulting spatial patterns of large-scale ligno-cellulosic energy crop cultivation with respect to their impacts on land and water resources. The authors report their calculated bioenergy potentials "are in the lower range of previous assessments," but they say all biomass sources may still provide some 15-25% of the world's future energy demand in 2050, with energy crops accounting for 20-60% of the total potential, depending on land availability and share of irrigated area. But therein lies the problem.

Noting that "human land use is already the most important driver behind environmental degradation (Foley *et al*., 2005), biodiversity loss (Butchart *et al*., 2010) and fresh water consumption (Rodell *et al*., 2009)"-and that "if energy crops are not restricted to abandoned and surplus agricultural land, the spatial expansion of agricultural activities could affect a large number of natural ecosystems, many of which already are under significant pressure from habitat loss and fragmentation"- the three German researchers conclude "a possible twofold increase in irrigation water requirements, global cropland increasing by up to 30% for energy crops alone, and additional nitrogen demand that may exceed future fertilizer production," all illustrate the great challenges of integrating large-scale bioenergy into global sustainable land use. In addition, they report "a spatial analysis with the 'Terrestrial Ecoregions of the World' data set (Olson *et al*., 2001) reveals that many of the affected regions feature a large diversity of wildlife," and "converting these iconic landscapes into large-scale biomass plantations may not be regarded as socially acceptable."

Another land-based concern with biofuels is the inadvertent introduction of invasive species that could negatively impact the natural landscape. In this regards, Witt (2010)[7] notes "several studies in the last five years have warned against the potential impact of promoting biofuel crops that are known to be invasive or to have potentially invasive characteristics," citing Raghu *et al*. (2006), Barney and DiTomaso (2008), Howard and Ziller (2008) and Buddenhagen *et al*.

[6] http://www.co2science.org/articles/V14/N36/B3.php.
[7] http://www.co2science.org/articles/V14/N6/B2.php.

(2009). He also states "a large number of proposed biofuel crops share the same traits as known invasive plant species," while indicating many of them "are already present in Africa." In light of these observations, Witt set out to assess the impacts of several species of the invasive *Prosopis* genus used for biofuel in Kenya and South Africa, where the spiny trees and shrubs have invaded over four million hectares of crop and pasture land.

Witt reports "communities in Kenya and elsewhere are becoming increasingly concerned about the displacement of other species important for local livelihoods, especially fodder species for livestock." They are also concerned, he continues, about their encroachment onto "paths, dwellings, water sources, farms and pastureland," as well as their "negative impacts on animal and human health with injuries due to thorns resulting in some human fatalities," as noted by Mwangi and Swallow (2005) and Maundu *et al*. (2009). In addition, Witt notes that the plants' tendency to invade riparian zones, dry river beds, and lowlands, where they "tap into underground water sources," means that they also "interfere with drainage, blocking watercourses and exacerbating the effects of flooding." And he states the displacement of native plants by *Prosopis* species is especially serious, noting "the World Health Organization estimates that up to 80% of the world's rural populations depend on [native] plants for their primary health care."

Witt concludes the importation and growing of nonnative species known to be invasive elsewhere, and that have been deemed to be high-risk species, "should not be introduced and cultivated," because "the costs associated with invasive species, even those that are deemed to be beneficial, in most cases, outweigh the benefits that accrue from their use," while ending with the *solemn warning* that "no widespread invasive plant species has been controlled through utilization alone in any part of the world."

In prefacing their work on the topic, Smith *et al*. (2013)[8] note "many of the most popular second generation crops proposed for cultivation in the U.S. and Canada are not native to North America," and "some are known to be invasive." Thus, Smith *et al*. (2013) opine "the

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[8] http://www.co2science.org/articles/V17/N4/B1.php.

development of a large-scale biofuel industry on the continent could lead to the widespread introduction, establishment, and spread of invasive plant species if invasive risks are not properly considered as part of biofuel policy." In light of these unwanted potentialities, Smith *et al*. (2013) evaluated "the risk of biological invasion posed by the emerging second generation biofuel industry in the U.S. and Canada by examining the invasive risk of candidate biofuel plant species, and reviewing existing biofuel policies to determine how well they address the issue of invasive species."

In describing their findings, the seven Canadian researchers say they uncovered evidence that "numerous potentially invasive plant species are being considered for biofuel production in the U.S. and Canada," yet they state the invasive risk of these projects "receives little to no attention in these countries' biofuel policies." They also identified "several barriers to integrating invasive species and biofuel policy, relating to policy analytical capacity, governance, and conflicting policy objectives." As a result, Smith *et al*. conclude by stating they "recommend that governments act now, while the second generation biofuel industry is in its infancy, to develop robust and proactive policy addressing invasive risk," noting "policy options to minimize biological invasions include banning the use of known invasive plant species, ongoing monitoring of approved species, and use of buffer zones around cultivated areas." And in closing, they warn "time is limited" and "if federal and provincial governments do not act soon, they will be faced with closing the barn door after the horse has bolted."

In a review article published in the *Journal of Plant Nutrition and Soil Science* (Lal, 2010[9]), Rattan Lal of the Carbon Management and Sequestration Center of Ohio State University (USA) introduces the subject of his concern by writing "the world is faced with the trilemma of climate change, food insecurity, and energy demand," because (1) "there still are more than one billion food-insecure people in the world (FAO, 2009a,b)," (2) "the world food supply will have to be doubled between 2005 and 2050 (Borlaug, 2009) because of the increase in population and change in dietary preferences," and (3) "the world energy demand is also increasing rapidly and is projected to increase by 84% by 2050 compared with 2005." And what makes the problem worse is that in the attempt to meet the anticipated increase in the global demand for energy, "the emphasis on biofuels is strongly impacting the availability of grains for food and soil resources for grain production."

Yet, as people are finally beginning to realize the significance of this latter problem, Lal indicates crop residues are being "widely considered as a source of lignocellulosic biomass." However, he writes removal of crop residues for this purpose "is not an option (Lal, 2007) because of the negative impacts of removal on soil quality, and increase in soil erosion (Lal, 1995)," as well as the loss of the residue's "positive impacts" on "numerous ecosystem services." Therefore, in yet another shift in tactics, Lal reports degraded soils are being considered as possible sites for establishing energy plantations. But he notes that with their extremely low capacity for biomass production, the amount of biofuel produced on globally-abandoned agricultural land cannot even meet 10% of the energy needs of North America, Europe, and Asia, citing the work of Campbell *et al*. (2009) in this regard. Yet even these considerations are only *half* the problem.

9 http://www.co2science.org/articles/V13/N41/EDIT.php.

In addition to the need for considerable *land*, Lal writes the "successful establishment of energy plantations also needs plant nutrients," as well as an "adequate supply of water." And the fact an adequate supply of water is something on the order of 1,000-3,500 liters per liter of biofuel produced is, as he puts it, "an important factor." And he notes this strategy will also "increase competition for limited land and water resources thereby increasing food crop and livestock prices (Wise *et al*., 2009)." In closing, Lal writes society must not take its precious resource base for granted, stating "if soils are not restored, crops will fail even if rains do not; hunger will perpetuate even with emphasis on biotechnology and genetically modified crops; civil strife and political instability will plague the developing world even with sermons on human rights and democratic ideals; and humanity will suffer even with great scientific strides."

In another paper touching on the subject of soils, Xue *et al*. (2011) "explored how annual clipping for biofuel feedstock production and warming caused soil erosion and accompanying carbon and nitrogen losses in tallgrass prairie" at the Kessler Farm Field Laboratory in McClain County, Oklahoma. In this "long-term field experiment," warming was provided by infrared heaters suspended 1.5 m above the ground as described by Kimball (2005), leading to air temperatures being raised by an average of 1.47°C and soil temperatures in the clipping plots by 1.98°C.

The results of the experiment revealed (1) the average relative depth of erosion caused by clipping was 1.65 and 0.54 mm/year, respectively, in the warmed and control plots from November 21, 1999 to April 21, 2009, (2) the soil erosion rate was 2,148 g/m^2/year in the warmed plots and 693 g/m^2/year in the control plots, (3) soil organic carbon was lost at a rate of 69.6 g/m^2/year in the warmed plots and 22.5 g/m^2/year in the control plots, and (4) total nitrogen was lost at a rate of 4.6 g/m^2/year in the warmed plots and 1.4 g/m^2/year in the control plots.

In discussing their findings, the five researchers say their results suggest "clipping for biofuel harvest results in significant soil erosion and accompanying losses of soil carbon and nitrogen, which is aggravated by warming." Further, according to Xue *et al*., "the amount of carbon and nitrogen loss caused by clipping is equivalent to, or even larger than, changes caused by global change factors." They also indicate "soil erosion is one of the most pressing global environmental challenges facing the world today, causing declining soil productivity and crop yields, which may cause difficulties in meeting the rising demand for food and energy (Brink *et al*., 1977; Brown, 1981, Lal, 2004; MEA, 2005)."

Lastly, in a review article published in *Frontiers in Ecology and the Environment*, Schiesari and Grillitsch (2011)[10] write about another potential negative impact of biofuel crops. They begin be noting the "global interest in biofuels in recent years is driving a continuous expansion of agro-industrial biofuel production all over the world (FAO, 2007)," and they say "to promote the acceptance of biofuels as a new energetic paradigm, governments and agro-industry claim that biofuels will have major environmental benefits as compared with benefits from conventional energy sources." However, in challenging these claims, the two researchers state industrialized agriculture "is one of the most important drivers of environmental degradation worldwide,"

[10] http://www.co2science.org/articles/V14/N32/EDIT.php.

reporting it "has caused large-scale contamination of soil, water and biota, through the extensive use of agro-chemicals, including pesticides and soil amendment products such as fertilizers (Clay 2004; OECD, 2008)." And they report "there is increasing concern that micropollution-characterized by low-level, multi-compound exposure-may suffice to elicit critical, potentially hazardous effects on environmental and human health (Schwarzenbach *et al*., 2006; Brock *et al*., 2009; EC 2009; OECD, 2009; US EPA, 2009)." Against this backdrop Schiesari and Grillitsch reviewed "the hazards imposed by all 784 pesticides currently registered for use on biofuel crops in Brazil."

In discussing their findings the two researchers say they detected compounds that have been "suspended by international conventions," as well as compounds that are included in databases and lists of priority concern that are "highly toxic in acute exposure, neurotoxic, probable or known carcinogens, known groundwater contaminants, and/or of known reproductive or developmental toxicity," some of which exhibit "endocrine-disrupting effects in humans and wildlife." Furthermore, Schiesari and Grillitsch suggest these chemicals will soon be employed "at increased rates, or for the first time, across large expanses of agro-industrially converted pastures and native (i.e., pristine) habitat in the *cerrado* (tropical savanna) and Amazonian rainforest biomes," which ecosystems will undoubtedly see great pressures exerted on the vast array of indigenous species of plants and animals that reside within them, perhaps driving some of them to extinction far before such a threat would ever materialize (if it ever occurs at all) as a result of the warming that is postulated to occur in response to rising atmospheric CO_2 concentrations, which phenomenon has actually been shown to help plants adapt to higher temperatures.

Industrialized agriculture is one of the most important drivers of environmental degradation worldwide. It has caused large-scale contamination of soil, water and biota, through the extensive use of agro-chemicals, including pesticides and soil amendment products such as fertilizers.

There is increasing concern that micropollution-characterized by low-level, multi-compound exposure-may suffice to elicit critical, potentially hazardous effects on environmental and human health.

In light of the several findings presented above, the host of intractable problems associated with large-scale bioenergy production will in all likelihood prevent their full potential from ever being realized. Strong competing interests for finite land and water resources will likely not allow it to happen.

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