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Biofuels: The Past, Present, and a New Vision for the Future

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Renewable biofuel production in the United States is dominated by ethanol from corn, billions of bushels of corn. Corn-based ethanol has marginal energy benefits and substantial environmental impacts, but it remains the only "viable" ethanol. That viability is largely due to subsidies and tariffs. Next-generation cellulosic ethanol was to be the future, but that future is not here yet. Nonethanol renewable energy processes may offer a more sustainable near-term future for cellulosic materials.

Grain-based ethanol, which in the United States is more than 95 percent from corn, fails the sustainability test on three fronts: economic, social, and environmental, though in this essay I will focus mainly on environmental sustainability. The United States produces 10.4 billion gallons per year (gpy) of corn ethanol, with 2 billion gpy of capacity idled and, surprisingly, 2 billion gpy under construction. Total capacity will soon approach the 15 billion gpy cap on corn ethanol, the allowed portion of the 36 billion gpy biofuel plan in the 2007 Energy Act. The rest is to come mainly from cellulosic sources. Since cellulosic ethanol is not commercially viable, grain ethanol proponents propose an extension of subsidies for their products beyond the 15 billion gpy cap. Many question such a proposal because of economic and environmental concerns.

Most scientists agree that grain-based ethanol causes direct and indirect environmental impacts. The current public debate, however, is about the indirect land-use effects, or the need to expand grain production to meet ethanol and feed demands. Expanded acreage causes new carbon emissions, habitat loss, and water-quality degradation. Some argue that technological advances will allow more efficient corn production, which will reduce the need for new acres. If that claim is true—and I question its accuracy—more intensive and efficient corn production, measured in "impact per bushel," as efficiency proponents suggest, will still intensify environmental impacts where the corn is produced.

Air-quality impacts and net energy gain are also concerns with grain-based ethanol. Corn ethanol has a small positive energy balance, so that each gallon of oil consumed in production results in 1.3 gallons of oil equivalent in ethanol. Such a small net gain makes the replacement of imported oil with grain ethanol unlikely. Less well documented are the air-quality impacts of grain-based ethanol. Production facilities have emissions, but so too does feedstock production. For corn, nitrogen oxide emissions are frequently substantial, so it is unclear whether grain ethanol reduces greenhouse gas emissions in comparison with gasoline.

My initial interest in ethanol was the water-quality impacts of expanded and intensified grain production. Corn is an annual crop that is an inefficient nitrogen (N) user. It loses more N to water than other commodity crops do. Soybeans, a legume usually in rotation with corn, also have high N losses from residual N. From 2006 to 2008, corn and soybean acreage in the United States increased by 10 million acres. Some acres were converted from cotton, but most came from land planted in hay, idle land, or land enrolled in the Conservation Reserve Program (CRP). Substantial CRP land coming out of long-term contracts was not reenrolled by farmers, which resulted in habitat loss, particularly in the prairies.

We estimate that with the expansion of corn and soybeans, 258 million pounds more N per year will be lost to the Gulf of Mexico (see *http://cip.cornell.edu/biofuels*), consistent with model estimates by others. Such increases are precisely the opposite of what is now needed: N loads to the Gulf need to be reduced by about 45 percent from pre-ethanol days. Monitoring data from the US Geological Survey indicate that 2007–2009 had near-record spring N loads, which fuel hypoxia in the Gulf. Water-quality impacts from expanded production appear real and substantial.

These facts put the sustainability of our current biofuels strategy in question. A new strategy is needed that includes both grains and perennial biomass crops in an integrated landscape-based approach. Biodiesel is often mentioned, but it will remain a minor source (about 1 billion gpy maximum, I estimate), mainly from waste food oils. So how do we get there from here?

To adapt James Carville's statement about the economy, "It's the biomass, stupid!" Perennial biomass crops, like switchgrass or fast-growing hardwoods, lose 75 to 90 percent less N to water, and they store carbon, reduce greenhouse gas emissions, provide habitat, and can be used to replace crude oil without conversion to ethanol.

We need to consider all options for energy from biomass that will reduce the demand for oil. For economic, social, and environmental reasons, community-based biomass facilities that can be sustained with 5 to 50,000 acres of biomass per year may be more sustainable than a large grain ethanol facility that uses corn from about 500,000 acres. Are there feasible nonethanol biofuel options at this smaller scale?

Biomass can replace oil in adapted boilers and burners for heating and energy production with adequate emissions controls. Is this viable? Virginia thinks so. The commonwealth has done test burns of switchgrass at a geriatric hospital, with very promising results. About 2500 acres of switchgrass would be needed to meet the annual needs of this hospital; 10,000 acres would be needed, then, to support community-scale biomass production in four locations. Converting oil-burning boilers, generators, and so on to equipment that uses fuel from wood or switchgrass has challenges, but it can be done, and probably with less subsidy than ethanol now commands.

Pyrolysis may be another viable biomass option that generates liquid biofuels. It involves anaerobic "combustion" of biomass under pressure at high temperatures to generate liquid biofuel and char, a fine-textured, charcoal-like product. The biofuel can be burned directly or refined for varying uses, including transportation fuel. Initial thoughts were to use small, portable pyrolysis units, but these highly engineered units may be better suited to a small-scale facility located to minimize biomass transport and storage. Such units may require biomass from 1000 to 5000 acres, with larger units where adequate land area for biomass production exists.

Plant nutrients and carbon are concentrated in the char, which can be used both as a nutrient source and for soil amendment. Research in the tropics has shown that char can lead to substantial improvement in productivity and soil quality, but more research is needed to assess the benefits of char for US cropland. The commercial viability of pyrolysis is unproven, although trials are promising, and, again, pyrolysis may require less subsidy than ethanol does.

Pyrolysis and direct combustion are the most promising of several biomass-to-energy conversion processes that could viably produce biofuels. They appear well suited for small-scale facilities, which could provide local social and economic benefits while enhancing environmental quality. Funding and subsidies to encourage research and investment in these near-term biofuel options are needed, as is continued work to make cellulosic ethanol viable.

My bottom line remains: "It's the biomass, stupid." A viable biofuel strategy must include a range of options for biomass use, and it must value the environmental benefits of perennial biomass production. Does this mean that we should close down all grain ethanol facilities? No, it does not. Our national and corporate investment is too large to allow us to abandon these facilities, but we should be cautious about further expansion. We will probably produce between 10 billion and 15 billion gpy of grain ethanol for the foreseeable future. Crop production to produce feed and ethanol feedstock can be part of an integrated, landscape-based biofuel strategy that includes row crops and perennial biomass managed to optimize feed and renewable energy production while minimizing environmental impacts.

We need to redesign the agricultural landscape to support multiple objectives, including renewable energy. Perennial grasses can be buffers around row crops to reduce N losses to water and air, to sequester carbon, and to provide habitat. They can also be grown on environmentally sensitive lands where row crops frequently are the least profitable and have the greatest environmental impacts. Perennial grasses for biomass grown on the right 10 to 20 percent of the agricultural landscape could do much to achieve needed water-quality improvements in the Gulf of Mexico and Chesapeake Bay, and would also help provide renewable energy with local social and economic benefits. Row crops on the remaining area could meet feed and grain ethanol demands. When cellulosic ethanol facilities become commercially viable, they could replace older grain ethanol facilities, creating more demand for biomass. This won't happen overnight, and there are limits to cropland conversion, given the domestic demand for feed.

We have the opportunity to embrace a more sustainable biofuel strategy. This sustainable strategy entails growing perennial biomass crops as feedstock for various biofuel options while allowing adequate row-crop production to meet feed and fuel needs. A redesigned agricultural landscape could produce food, feed, and fuel and at the same time improve water, air, and habitat quality. Let me stress: This would be a biofuel strategy, not an ethanol strategy.

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