Decrypting Biofuel Scenarios

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Decrypting Biofuel Scenarios

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An energy–food–environment maelstrom, and a prairie plan

Biofuel's the thing, the new universal solvent, the energy elixir, the great wet hope. Your next car—or maybe the one after—could run on corn, or soybeans, or old pizza boxes. The feds say biofuel will break our addiction to oil from the Mideast, and farmers say it'll revive rural economies in the Midwest. The biotechnologists, venture capitalists, and geopolitical strategists, the operators of hedge funds and of grain elevators, and many of the rest of us, from Bush to Barack, are fascinated.

Biofuel music of a more questioning, minor-key character is increasingly audible in the mix, though. What about the environmental and social effects of lurching, on a gigantic scale, from one energy technology to another? What's it all going to cost? "A number of drivers out there on the world stage are forcing Americans to look at renewable fuels—everything from national energy security to foreign policy to climate change," says Larry Walker, a bioprocess engineer at Cornell who has been working on fuels systems since 1979. "The questions are, can we do these things cost-effectively, and in an environmentally sustainable way?"

Several factors have already nudged US agriculture toward production of ethanol from corn. Estimates of the myriad federal subsidies vary, but they range from a hefty 87 cents per gallon to something north of $1.65. Add in rising oil prices, exhortations in two successive State of the Union messages, and new federal requirements that refiners blend billions of gallons of ethanol with gasoline. Ethanol plant capacity jumped 34 percent during 2005 and 2006 alone, and new construction already under way is slated to double that capacity again when it's complete. The chief economist at the US Department of Agriculture (USDA) has called this "the most stunning development in agricultural markets today."

The rapid shift toward biofuels pushes environmental and social issues forward, along with the need for some rational way to account for them in making policy. According to a consensus of recent research studies, biofuels may offer profound opportunities to improve current trends affecting the environment. But, as with fossil fuels or any other widespread technology, this form of energy may generate its own ill effects, including these:

- diversion of food crops such as corn and soybeans into gas tanks, as biofuels
- release of greenhouse gases

- conversion of wildlife habitat, including rainforests, into "energy-crop" farmland
- accelerating soil depletion
- drawdown of scarce water resources for irrigation
- the spread of invasive species used as energy crops
- the illusion of sustainability despite extravagant energy consumption
- more use of groundwater-polluting agricultural pesticides, herbicides, and fertilizers, which have already turned the Mississippi, in particular, into a sluice of poisons responsible for the Connecticut-sized "dead zone" in the Gulf of Mexico

It may be hard to imagine worrying usefully about this whole list, but ecologists and economists are increasingly ambitious in trying. They often rely on a kind of modeling called "life cycle analysis" or "life cycle assessment" (LCA). Definitions differ, but the LCA idea is expressed in slogans like "cradle to grave" and "farm to fork." It's an attempt to quantify the environmental and economic impacts of making, consuming, and disposing of a product to answer comparison questions: plastic diapers versus cloth, plastic bags versus paper, gasoline versus biofuel.

Reckoning tortillas, invasives

First, some basics. The most common biofuels are ethanol and biodiesel. Most US ethanol is produced by fermenting sugar derived from cornstarch. Biodiesel can be refined from soybeans, rapeseed, and other plants.

Biofuels aren't the sole answer for achieving energy independence or for improving the outlook for the environment. They cannot come close to replacing the United States' fast-growing consumption of energy, projected to increase 25 percent by 2030. If the whole of the current US soybean and corn crops were diverted to biofuel production, they would satisfy only about 6 percent of the demand for diesel and 12 percent of the demand for gasoline.

John Sheehan, a senior strategic analyst at the federal National Renewable Energy Laboratory in Colorado, says, "It is an unsustainable proposition to suggest that biofuels or any other alternative fuel can meet current energy appetites. That's simply not feasible. So if you really want to get rid of oil, it comes to a large extent from vehicle efficiency improvements and 'smart growth' improvements, along with alternative fuels."

Cellulosic ethanol is the next generation of biofuel technology. As a competitive fuel source, it may be three years off or a decade or more, depending on who's prophesying. All green plants and their derivatives—cornstalks, cardboard, manure, sawdust, the organic components of municipal garbage—contain lignocellulose. Special enzymes are used to separate the lignin from the cellulose, which yields sugars that can be refined into ethanol.

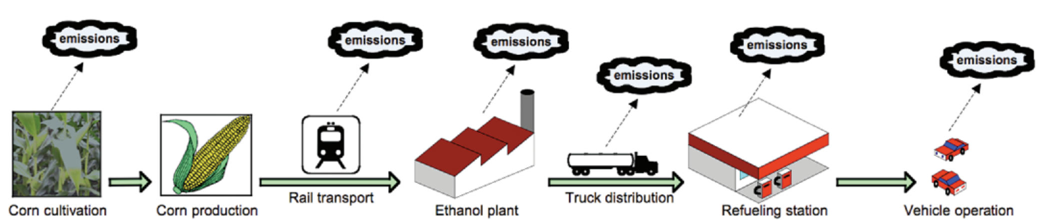
Cellulosic ethanol is already produced on a modest scale at one plant near Ottawa, Canada; other plants are on the drawing boards in Iowa, New York, South Carolina, and elsewhere. They are supported by a brisk in-migration of venture capital and up to $385 million over the next four years from the US Department of Energy, as well as other federal subsidies and some state-level funding. The surge in public and private investment entails risks. The costs to develop the technology and then to produce and distribute the fuel are not known, but promoters say additional large-scale public subsidies will be needed.

Cellulosic ethanol has sparked interest in various fast-growing "energy crops," but some of those have disturbing potential as invasive species. Specialists say native switchgrass, featured in the last State of the Union message, may be invasive if introduced outside its natural range. Aggressive alien invasives such as *Miscanthus* grass or *Arundo donax,* a giant Asian reed, have also been proposed.

A major promise of cellulosic ethanol production from waste is that it would avoid the "food versus fuel" issue, whose significance is mushrooming. The USDA projects that the fraction of US corn used for ethanol will double from 2005 to 2007, when it will consume 27 percent of the crop. Much of that increase is in turn subtracted from US corn exports, which make up 70 percent of worldwide corn exports. As a result, corn prices nearly doubled from January 2006 to January 2007, and world markets were rocked. Tens of thousands rioted in Mexico in February to protest the price of corn tortilla flour, a national staple, threatening to destabilize the government. Investor fever has played a role, says Chad Hart, an agricultural economist at Iowa State University, but of all the factors spiking corn prices, "everybody would point to ethanol as the major driver there."

The petroleum industry has said that burning food in our fuel tanks is "morally inappropriate" while there's starvation in the world. The National Corn Growers Association, meanwhile, denounces these concerns as "patently false and misguided, as US producers will continue to adequately supply all markets with high quality corn." Indeed, farmers have responded to the phenomenal market for corn. The spring forecast for US acreage planted in corn is 15 percent higher than last year. Corn prices fell by a like percentage at the news.

That's not enough of a drop to make the food-cost issue go away, though. And



according to the USDA, most of that "new" corn acreage is on land planted last year in two other food crops: rice and soybeans.

Life cycling

Maybe your take is that only free-market economics can impose good order on the Rubik's cube of factors scattered through oil, environment, and agriculture questions, or that corporate lobbyists will ultimately make policy. If so, then the government's role is unwelcome or moot. But if the government acts in the wider public interest on biofuels issues, there's a different challenge: to decipher the tangle of counterclaims and heaps of data. LCAs are increasingly a part of such planning efforts.

In comparing biofuel options, the ledgers of even the simpler LCAs account in detail for a long list of energy and material inputs, including fossil fuels, for producing an energy crop, processing it into ethanol or biodiesel, and distributing it. Also included are the energy and resources it takes to manufacture the fertilizers, pesticides, tractors, combines, trucks, and other equipment, and, in some studies, the energy it takes for farmers to live or for their labor force to commute to work. Other LCAs have evolved beyond comparing energy returns to account for at least some outputs—especially environmental effects.

"Life cycle analyses are taken seriously," says Sheehan, who has appeared before a congressional hearing to talk about biofuels in LCA terms. "Those kinds of studies do find their way into policy." The question underlying all the LCAs about biofuel may sound familiar: Does producing it use more energy, especially fossil fuel energy, than it displaces?

Back in 1980, during the first Mideast oil crisis, the Department of Energy appointed David Pimentel to work that out, "because there was so much misinformation. And I must admit the situation hasn't changed a hell of a lot," Pimentel says now. The headline on a recent university press release sums up the research he and his collaborators have done on the subject: "Cornell ecologist's study finds that producing ethanol and biodiesel from corn and other crops is not worth the energy." He has also concluded that cellulosic ethanol is a losing proposition.

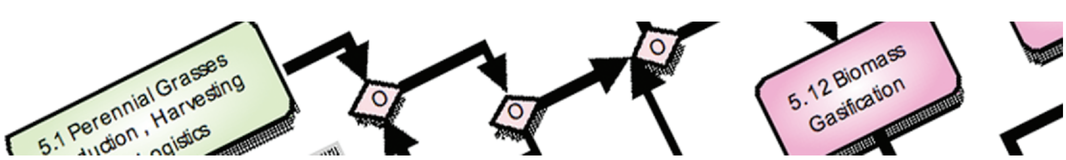
Arrayed against the Pimentel position are studies by the US Departments of Energy and Agriculture (both self-professed promoters of biofuels) and related agencies such as the Argonne National Laboratory; by major environmental groups such as the Natural Resources Defense Council and the Union of Concerned Scientists; by agricultural and industrial trade associations linked to biofuels; and by a heavy preponderance of peer-reviewed LCAs, and comparisons of them, published by independent, university-based researchers in a variety of journals. They have concluded, to varying degrees, that biofuels are indeed "worth it."

A still-developing mode of inquiry, LCAs have their methodological and theoretical vexations, and the biofuels boom has highlighted some of them. One major issue is that boundaries for studies are necessarily drawn somewhat arbitrarily. Is it fair to include the caloric intake of farm workers versus oil workers (farming is more labor-intensive)? Then there's the matter of competing values, which LCAs can't really help with. If one kind of biofuel speeds us toward energy independence more quickly, is it okay to sacrifice natural areas? Is groundwater pollution more important than air pollution?

Mark Delucchi is a research scientist at the Institute of Transportation Studies at the University of California–Davis who has published several LCAs, including one of the first comprehensive assessments of alternative transportation fuels. He says the field needs to push much further to be useful for judging policy questions. "It's not enough to have an orderly accounting of energy yields," he says. "You have to figure out the effects of biofuels on natural systems and on markets worldwide, and no LCAs do this."

By this logic, if you draw the boundaries of your model short of economic effects, or just at the borders of the United States, your analysis is something of a fantasy—as if you were trying to predict the weather without looking at patterns outside your own city. Instead, Delucchi says, "you have to start with the broadest possible system in the longest possible time frame, and then ask yourself, What's the most we can simplify it without losing so much representational robustness that we can no longer be sure that we are adequately representing reality?

"This is a very complex problem. We have a system of globally traded commodities, agricultural products, energy products, and global, long-term natural



effects.... So the system boundary is the geophysical and economic system of planet Earth. There's no getting around that. That's what the problem is."

Other practitioners argue that LCAs will never achieve that kind of complexity. "Yeah, there are lots of those people, and I'm one of them, in a way," Delucchi says. "It's not clear that we can ever be sure that we're adequately describing all of the relevant factors. We should be modest in how we present our results, and acknowledge that.

"There have been big surprises. In the environment, in energy, all of the big shifts happened as a result of unpredicted events—OPEC, Rachel Carson, the fall of the Shah of Iran, the nuclear accidents—they were certainly outside of the normal modeling framework."

David Pimentel, emeritus professor of ecology at Cornell University, has taken the controversial position that growing crops to provide fuel squanders resources. Photograph: Cornell University Photography.

Sheehan agrees that a comprehensive LCA needs to try to include the economic implications of a proposed change. "The problem is this world model. While that's the ideal, it simply isn't practicable. I'd love to be able to model the world, but, you know, nobody's gotten there quite yet.... It's a little like arguing that just because we can't know this perfectly, we shouldn't try to know it at all."

A Cedar Creek microcosm

The 23 square kilometers of Cedar Creek Natural History Area are a gift to the University of Minnesota, a few kilometers northeast of the Twin Cities. Two-thirds of it is devoted to native plants, including prairie of the kind that has been all but erased from the continent by the plow during the past two centuries.

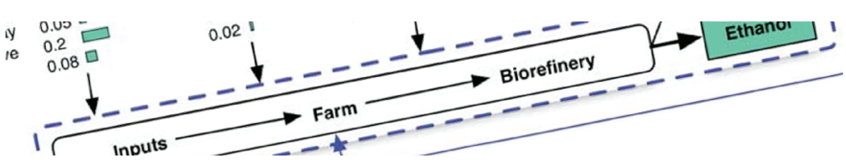
University of Minnesota ecologist David Tilman has been comparing the characteristics of multispecies ecosystems with biologically impoverished ones there for the past 25 years. His experimental studies have found that the more diverse the ecosystem, the more resistant it is to the alien invasive plants that have overtaken millions of Midwest hectares. Diverse ecosystems also produce more biomass and are more resilient in the face of natural disturbances such as drought, fire, flood, and disease.

Just as noteworthy is the fact that the perennial grasses that make up most of the prairie ecosystems sprout massive root systems that enlarge over time. As they do, they incorporate carbon dioxide (CO_2) absorbed from the atmosphere. Tilman's research has found that prairies, even if they're burned off or harvested for other uses each year, are pulling more CO_2 out of the atmosphere than they add to it, in contrast with corn and soybean agriculture.

Tilman was a coauthor of two recently published LCAs. One compares various fuels in terms of their energy yield and a series of environmental effects (*Proceedings of the National Academy of Sciences*, 25 July 2006). The other prescribes a feedstock for cellulosic ethanol that could, if it worked, answer a long list of environmental concerns (*Science*, 8 December 2006).

The first study ranks biofuels: Corn ethanol yields 23 percent more energy than is needed to produce it; biodiesel

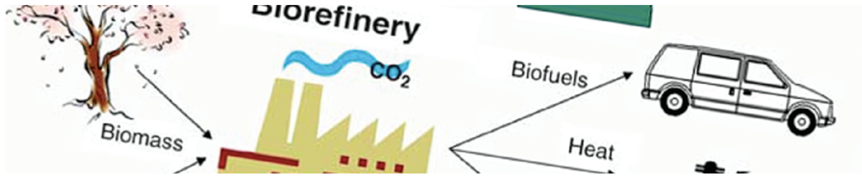
Research by David Tilman, an ecologist at the University of Minnesota, concludes that prairies can be a source of energy while providing "restored habitat for many native plants, insects, animals, birds, mammals, fungi, and bacteria." Photograph: Gary Bistram, Bistram Photography, Inc.



In February, President Bush toured the Novozymes lab in Franklinton, North Carolina, to promote his new biofuels plan. Photograph: White House/ Paul Morse.

returns 93 percent. Cellulosic ethanol beats both. Compared with fossil fuels, greenhouse gas emissions are reduced 12 percent by the production and combustion of corn ethanol and 41 percent by biodiesel. The study went on to compare fuel production in terms of several kinds of pesticides, water and air pollutants, and greenhouse gas emissions. Cellulosic ethanol showed to advantage in every category.

That set the stage for the publication soon afterward of a study in which Tilman and collaborators linked his earlier research on prairie perennial grasses to cellulosic ethanol. It makes the prairie ecosystem look like a near-miracle: a source of nonfood energy and wildlife habitat that sharply diminishes greenhouse gas emissions; avoids irrigation, as well as pesticide, herbicide, and fertilizer pollutants; and provides resistance to invasives. He calls these ecosystems "low input, high diversity" (LIHD) biofuel sources. If they were grown on the degraded soils set aside under federal



conservation programs, they wouldn't even displace food crops. And, the study concluded, they would produce a net energy gain per hectare 50 percent greater than corn grain ethanol from prime soils.

"A first step," Tilman says, "would be allowing farmers to mow their current Conservation Reserve Program grassland for the energy in its hay, and there's 35 million or so acres of that land." It could be seeded with prairie species that would be dominant within five years. During the first decade, they build up an immense carbon-sequestering root system. Root growth levels off, but the soil continues to sequester carbon for about a century. Because few or no resource and energy inputs are needed to prod growth, the study's LCA balance sheets make prairie-grass ethanol look like a bargain compared with other waste-based biomass sources, such as cornstalks.

"The idea is that the native species are the best adapted for this climate, the soils, and the pests, and they would also make a very good habitat for the other native species and therefore have a wildlife benefit. It provides restored habitat for many native plants, insects, animals, birds, mammals, fungi, and bacteria," Tilman says. The carbon sequestration effect means that LIHD biofuels would reduce greenhouse gas emissions 6 to 16 times more than corn ethanol or soybean diesel would, if substituted for fossil fuels.

Tilman was invited to meet with several House and Senate groups and a committee chairman during a recent trip to Washington, DC. But among those seeking biofuel subsidies from Congress, the prairie-grass lobby may not have a lot of voltage.

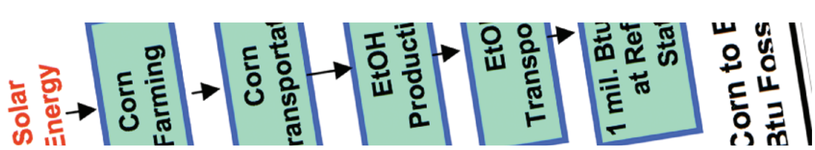
Tilman is unfazed. "Ideas don't make it because they sound too good to be true, but because they are actually economically viable," he says. "What you have to ask is, how much profit can a farmer make growing and selling prairie biomass for an energy crop compared to growing corn or soybeans or some other grain? The biggest challenge is to try to find a way that the farmers are rewarded for all the services they are providing to society."

Walker says Tilman's work has caused a stir, even in a field that's already stimulated. "I'm very excited about it, and I think some of my colleagues here in New York are, partly because it applies to the environment we have here," he says. "Many of the grasses reported in that study, we can grow here."

Demurrers have been filed, of course. Tilman's study proposed a long-known gasification process to squeeze ethanol from the grasses. But its economics can't be gauged until a large-scale, real-world plant is in operation using these species, Sheehan says. The alternative process would require a complex cocktail of enzymes that are, as yet, unconjured and unpriced.

Ken Cassman, a systems agronomist at the University of Nebraska and director of the Nebraska Center for Energy Sciences Research, faults the Tilman study for its conclusion that prairie biomass can sustain annual harvests with little fertilization. "It remains to be determined whether this is practical," Cassman says.

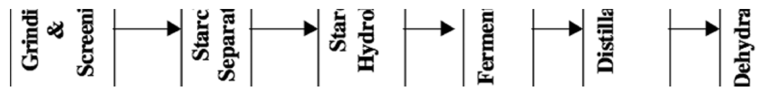
Tilman responds that his work is presented only as a first step, the basis for further experiment. But studies of unfertilized prairies that have been



mowed for decades show that they are still producing biomass reliably, he says, adding that his research accounts for losses of soil nutrients that could affect production.

Feasible or not, Tilman's proposal breaks new ground by responding to a far more ambitious list of ecosystem and economic issues than other LCAs—especially those, still widely cited, that are limited to just "oil versus biofuels" energy comparisons.

Cassman and other researchers have another, more general concern: the effect of biofuel on the R&D environment. "I think we're in a place where there's so much excitement about biofuels right now, and a lot of money being thrown at research and investment," he says. "We could really end up



in five or ten years with a potential boom and bust cycle. It wouldn't be good for the industry or for the country, if we don't invest carefully in directing that research to the most promising options."

Bricolage graphics: Steve Nash.

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