



COMMUNITY ESSAY

Can biotech companies enable ethanol biofuels to achieve sustainability?

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Author's Personal Statement:

This article is based on my readings and interviews during an Energy Forum in Lucerne, Switzerland in 2007. The forum was unlike any scientific meeting that I had previously attended in that the participants were passionate in their commitment and many of the talks had a strong sense of advocacy. I was struck by the concern, the sense of immediacy, and the "out of the box" proposals presented.

While elegant molecular biology-based approaches to energy self-sufficiency are an essential component of the solution to the world's energy problems, even their most fervent supporters admit widespread application is years into the future. In the interim, I believe that it is absolutely essential that we consider energy alternatives that could bring about immediate energy and carbon-dioxide savings.

I find it ironic that today Americans are hammered by rising energy prices, yet no politician has suggested conservation as a respite from the run up in energy costs. I hope that this review will help to stimulate informed debate and realistic solutions to the current energy dilemma in which we are mired.

Introduction

A perfect storm of forces has coalesced to send world corn-ethanol production through the roof. Driven by insatiable consumer appetite, fears of global warming, political pressures by agricultural conglomerates, and high prices for petroleum from unstable regions of the world, biofuel production—principally corn-based ethanol—has increased prodigiously in the last few years. The United States Department of Agriculture (USDA) predicts that corn-ethanol production will reach 10 billion gallons by 2009, up from 5 billion gallons in 2006 (Westcott, 2007a).

Yet, there probably is no more controversial technology for generating sustainable fuels. Political, economic, and scientific problems challenge the viability of corn-based ethanol as a major alternative to gasoline. As these concerns multiply, alternative schemes for satisfying the exploding demand for automobile fuel have acquired new appeal. Hoping to ride on the crest of this wave are academic scientists and biotechnology companies pushing what they believe to be a greener, more efficient alternative to traditional farming practices and industrial-scale fermentation processes for generating biofuels.

Biofuel production, of course, is not new. Brazil's program, based on cane sugar, goes back three decades. Using conventional agricultural and fer-

mentation technology, Brazilian ethanol production of 3.1 billion gallons accounts for 15% of the country's total liquid fuel supply (Valdes, 2007). With government subsidies and higher yields per hectare of cane versus corn, this strategy has been viable in Brazil, but was never seriously entertained in the United States where corn has been the main source of sugar for fermentation into ethanol.

Contemporary biofuel technology has received added impetus from advances in molecular biology that make available a variety of tactics for improving productivity. These options include genetic engineering and the redesign of plant architecture to improve productivity or alternatively targeting the organisms responsible for the fermentation process to increase robustness and improve fermentation efficiency (Stephanopoulos, 2007).

Biotech Presence in Biofuel Technology

Codon Devices, based in Cambridge, Massachusetts, is one of a number of firms currently seeking to optimize gene designs for specific applications related to biofuel production (Codon Devices, 2007). The firm provides "operon variant libraries" for screening and selection in metabolic engineering. Such libraries are collections of DNA sequences retained in bacterial plasmids that run the gamut of multiple promoters, terminators, and genes pulled in

from different families. The libraries can be extracted, manipulated, and inserted into plant genomes so as to optimize synthetic performance of the plant strain. According to press releases, the firm has signed an agreement with another company, Agrivida, for the discovery, development, and commercialization of engineered proteins for use in biofuel applications (Agrivida, 2006).

The latter firm, an agricultural biotechnology company, will use the Codon Devices platform to develop enzymes optimized in corn varieties for ethanol production. Since conventional methods for manufacturing ethanol use the corn grain only, leaving the remaining cellulosic material in the field, the use of the entire plant should greatly improve efficiency and yield per hectare.

Agrivida claims the collaborative work between the two companies would utilize the remaining 50% of the total biomass yield per acre of farmland, which currently is lost in production (Agrivida, 2006b). Central to the firm's ethanol-optimized corn technology are engineered enzymes that are incorporated into the corn plants themselves. These enzymes will efficiently degrade the entire mass of plant material into small sugars that can then be readily converted to ethanol. The optimized enzymes that Codon Devices is developing will allow Agrivida to further improve the degradation process throughout the entire plant, promising significant improvements to ethanol production. This process could dramatically improve ethanol yields. The partnership between a firm specializing in recombinant DNA manipulation and a company with experience in plant manipulation seems ideal here, allowing Agrivida to dramatically enhance the volume of ethanol through cellulose degradation.

The Codon Devices/Agrivida program takes on the thorny problem of biomass recalcitrance, that is, the natural resistance of plant-cell walls to microbial and enzymatic breakdown, which currently renders the industrial-scale production of ethanol from biomass material unachievable (Himmel et al. 2007). Plants have evolved an extremely complex array of structural and chemical devices to protect them from external assault, including epidermal tissue, vascular bundles, thick wall tissues, and molecular arrays of microfibrils and polymers, all of which constitute a formidable series of barriers. Current conversion technology is costly, complex, and energy intensive (Koonin, 2006).

Overcoming these roadblocks to cost-effective biomass conversion will require a variety of approaches, including new ways for removing lignins and hemicellulose, as well as disassembling the cell at the nanoscale to allow the penetration of pretreatment chemicals and hydrolytic enzymes. Moreover, other

biotechnology companies are pursuing strategies to genetically engineer the plant cell so as to make it more amenable to chemical and enzymatic digestion.

However, such proposals to radically redesign plant-cell walls to make them more receptive to cellulosic conversion are challenging and fraught with peril. It is likely that modifying the plant-cell wall would make the plant more fragile and subject to structural failure and sensitivity to fungal pathogens (Palmer, 2007). In addition, a number of estimates have been made of energy yields from biofuels, a hornet's nest of controversy. Hill et al. (2006) calculate that corn ethanol yields 25% more energy than that invested in its production, whereas biodiesel yields 93% more energy. Pimentel et al. (2007) report estimates of corn-ethanol energy yields that challenge these claims and conclude that with current technology, 1.43 kilocalories (kcal) of fossil energy is expended for every 1 kcal of ethanol generated. They further contend that previous estimates ignored various energy inputs (transport equipment and other farm machinery) and generate an inaccurately optimistic estimate of the net overall energy yield in corn-ethanol production. Farrell et al. (2006) compared a number of different studies and, while estimates of energy ratios varied, argue that ethanol produced from switchgrass would be much more favorable in terms of its production of greenhouse-gas emissions. But all commentators agree that large-scale biofuel generation from corn or soybeans cannot replace much petroleum without drastically affecting food supplies. The draconian move of dedicating all United States corn and soybean production to biofuels would meet only 12% of gasoline and 6% of diesel demand (Farrell et al. 2006).

Indeed, the dramatic increase in corn-ethanol production appears already to be driving up farm commodity prices. According to USDA, corn prices have risen sharply, from \$1.75/bushel in 2000 to \$3.50/bushel in July of 2007 and to \$6.00/bushel in the first half of 2008 and these market dynamics have driven up prices of other crops and meat (Westcott, 2007b; Associated Press, 2008). For the foreseeable future, food prices can be expected to rise faster than the general rate of inflation. There is general agreement throughout academic and commercial sectors that 12 to 15 billion gallons of ethanol is the maximum that could be produced from corn without severe disruption of the entire price structure for farm commodities (Pimental et al. 2007).

Even beyond today's inefficient methods, a serious objection remains to technologies that convert all the components of the corn plant (i.e., leaves, stems, roots) to a source of cellulosic material for conversion to sugar. Such a process would return zero nutrients to the soil. In addition, the presence of

these materials on the field protects from wind erosion. Standard farming practices use the unproductive components of the plant as fertilizer for the next year's crop by mechanically crushing and recycling at least 50% of the unharvested portions (known as corn stover). If this cycle is interrupted, farmers will essentially be mining their fields and the only way to maintain productivity will be by application of synthetic fertilizers. Such activity raises the energy requirements of production to a negative energy balance, comparable to current corn-production technology (Pimental et al. 2007). Indeed, any scheme based on recovering all of the plant material from annual crops will eventually collapse as a failed perpetual motion machine. In addition, the infrastructure for marketing, transporting, and storing corn stover does not exist and will require years to construct.

The case for ethanol production from grasses or woody material is more appealing from the energy-balance standpoint. An authoritative and carefully researched study carried out under the auspices of the Oak Ridge National Laboratory documents that a billion tons of biomass is available for conversion to biofuel without serious economic, environmental, or agricultural disruption (Perlack et al. 2006). The Cambridge-based Mascoma Corporation is building demonstration facilities to convert waste biomass into ethanol. The company has developed technology for improving the early steps in the process, including the removal of the lignin that shields the cellulose, and the next phase, the conversion of cellulose to sugar through an improved enzyme cocktail. The firm estimates that this technology could produce ethanol from wood chips for about the same price as from corn, and eventually for much less (Mascoma, 2008). However, there are still daunting basic scientific and technical problems. Himmel et al. (2007) estimate that developing biomass conversion for cost-effective motor-fuel production could be realized by 2030.

Verenium, a company recently formed from the merger of Diversa and Celunol, is also seeking to develop a cellulosic biofuels program (Verenium, 2007). The firm has developed enzyme products for the conversion of plant material, including corn and agricultural waste, into ethanol. Its first biofuels product, Fuelzyme™-LF enzyme, is intended to increase the efficiency of ethanol production from corn. This product is an LF alpha-amylase designed to increase the throughput of corn, providing superior liquefaction. A second product, Fuelzyme™-CX, is aimed at the conversion of cellulosic biomass to ethanol. The company is developing industrial-scale facilities for cellulosic ethanol production and by 2010 intends to have a plant that will produce 25 to

30 million gallons annually. Its business plan outlines a long-term commitment to alternative fuels.

Controversial Issues in Biofuel Development

Much of the controversy currently surrounding biofuels may result from overreaching promotion that can never be fulfilled. According to Righelato & Spracklen (2007), critical issues need to be considered when weighing the efficacy of biofuels as mitigators of fossil-fuel emissions. Since vast amounts of agricultural acreage would have to be taken over to grow crops for biofuels, one needs to calculate the loss of carbon sequestration due to changes in land use. These authors calculate that a 10% substitution of gasoline and diesel fuel by biofuels would require 43% and 38% of the current crop land in the United States and the European Union (as the European Union was comprised in 2001) respectively. Since this reallocation would cause a loss of almost half of United States food production capacity, huge tracts of forest and grassland would have to be converted to crop production with attendant loss of carbon storage. Righelato & Spracklen (2007) further estimate that in all cases forestation will sequester two to nine times the amount of carbon emissions avoided by biofuels raised on this land over a 30-year period. They furthermore argue that if the object of biofuels policy is to decrease carbon dioxide (CO₂)-induced global warming, a much better approach would be to increase conservation of fossil fuels and, at the same time, restore and conserve natural forests and savannahs.

In the same vein, Berkeley petroleum engineer Tad Patzek has recently argued that the economic, environmental, and social costs exacted by a massive corn-ethanol program would far outweigh the benefits obtained.¹ A number of other presentations at the same forum counsel conservation.

Indeed, if a massive biofuels program achieved 30% of United States automobile fuel needs by 2030, the amount by which petroleum use would be decreased would be much less than that which could be obtained by replacing American cars with their European model counterparts. At present, select European models average 52 miles per gallon (mpg) versus 32 mpg for the American version of the same car. Accordingly, the European automobile fleet obtains 61% better mileage than the same models manufactured for the United States market due to the substitution of highly efficient diesel engines and manual

¹Presentation at the European Sustainable Energy Forum, July 3 to 6, 2007, Lucerne, Switzerland. See <http://www.efcf.com>.

transmissions.² Since there are more carbon atoms per gallon of diesel (12-16 carbon atoms/molecule) as compared to gasoline (approximately 8 atoms/molecule), CO₂ mitigation from the diesel fuel itself would be limited (Bullis, 2006). However, there would be tremendous savings of petroleum resources from the conversion to diesel fuel as well as from manual transmissions and other energy-saving features that could decrease automotive CO₂ emissions. These calculations (ca. 60% fuel reduction with automobile fleet changeover versus 30% reduction with massive biofuels program) clearly favor conservation over biofuels and business as usual.

There are, of course, many other strategies for improving mileage performance in automobiles and it would likely be much more effective to target tax credits toward fuel-efficient vehicles than to invest the same amount of taxpayer dollars in ethanol price supports. The counterargument is that both strategies should be adopted, but on a short-term basis a proven, immediately available technology is preferable to a long-term, untested proposition with substantial environmental costs.

So if corn ethanol is technically an energy sink and economically a black hole—and biomass ethanol is years away from commercialization—where does that leave the industry? All indications are that the strategy has shifted back to the political arena where the short-term push toward corn-based biofuels may prove unstoppable, despite the lack of scientific or economic practicality (Rosenthal, 2007; Martin, 2008). Not only are major tax incentives being promoted at the federal level in the United States, but many states, such as North Carolina, Iowa, and Ohio, have their own biofuels initiatives that include large tax breaks and subsidies.

Backers of corn ethanol (agribusiness and politicians from farm states) have been forced to admit that corn ethanol does not make much sense, but argue that producing corn ethanol will add to the infrastructure for transportation and storage, as well as consumer acceptance, of ethanol. Matthew Wald (2006) stated a couple of years ago that “[b]ackers defend corn ethanol as a bridge technology to cellulose ethanol, but for the moment it is a bridge to nowhere.” While this observation may reflect a degree of hyperbole, the program as it now stands raises serious concerns that need to be answered before the country embarks upon a program costing billions and billions of dollars. It does not appear that these con-

cerns can be allayed by application of elegant genetic engineering technologies.

Author's Note

The information concerning biotechnology companies and their research programs was obtained from company websites and press releases. As a caveat, it should be stressed that this information is available in the public domain, but is based on the claims of corporate representatives and other public pronouncements rather than peer-reviewed journal articles. While descriptions of currently available technology are verifiable, predictions for future goals must be considered hypothetical.

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² See <http://www.gas-cost.net>. The website claims that “across the board, European models get an average of 52 miles per gallon (MPG) versus 32 MPG for the US version of the same car. So the [European version of the] same car...gets 60% better gas mileage than” the American version.

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