Reference

1. Much of this evidence comes from results of U.S. Department of Agriculture (USDA) Crop Development Center, Land Grant Institution, and U.S. Department of Energy– and USDA-funded research.

Energy Returns on Ethanol Production

IN THEIR REPORT "ETHANOL CAN CONTRIBUTE to energy and environmental goals" (27 Jan., p. 506), A. E. Farrell *et al.* focus in part on whether biomass-derived ethanol fuel delivers positive net energy [i.e., whether energy return on energy invested (EROI) exceeds 1:1; see (*1*)]. Their analysis neither resolves nor clarifies the fundamental issues that make net energy important and contentious. First, in their comparison of ethanol and gasoline, they confuse EROI—a productivity index—with the energy efficiency of an oil refinery. Second, their use of energy break-even as a litmus test is a red herring; it is more crucial that EROI is high compared with competing energy sources. Exploration for domestic petroleum in the 1930s returned 100 Joules for each Joule invested; the EROI for oil production today is ~15:1 (*2*). Because the present EROI of fossil fuels is high, the ~90 net Quads (1 Quad = ~1 exajoule) delivered annually to the U.S. economy results from an investment of only about 10 Quads (*2*). To provide that same 90 net Quads from corn-derived ethanol would require an investment of 145 to 500 Quads (based on an EROI = ~1.6:1 to 1.2:1, implied by Farrell *et al.*'s fig. 1). The current transportation system cannot be maintained on a fuel system delivering only a 1.6:1 return. Third, the focus on petroleum inputs is too limited. Natural gas is often the principal input to biomass fuel production, but its future is no more certain than oil's; we already import more than 15% of what we use (*3*). Fourth, the authors ignore the energy cost of repairing soil erosion.

Finally, the one (speculative) result for an energy technology based on cellulose in fig. 1 implies an EROI of ~50:1. This (very uncertain) EROI indicates that this source of biomass could be potentially useful, but ethanol from corn remains too marginal to survive without heavy economic subsidy.

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References

1. C. J. Cleveland, R. Costanza, C. A. S. Hall, R. Kaufmann, *Science* **225**, 890 (1984).
2. C. J. Cleveland, *Energy* **30**, 769 (2005).
3. Official U.S. Energy Information Web page, eia.doe.gov.

IN THEIR REPORT "ETHANOL CAN CONTRIBUTE to energy and environmental goals" (27 Jan., p. 506), A. E. Farrell and colleagues offer hopeful opinions about corn-based ethanol. Their analysis suggests that, since the ratio of ethanol produced to fossil fuel used is positive, ethanol should be further developed. If replacing oil is our goal, we must look at two parameters of this approach: (i) energy return on investment (EROI) including environmental impacts on soil, water, climate change, ecosystem services, etc.; and (ii) scalability and timing. Farrell and colleagues' most optimistic EROI of 1.2:1 (which does not include tractors, labor, or environmental impacts) implies that we need to produce 6 MJ of ethanol to net 1 MJ of energy for other endeavors. Thus, the yield of ethanol would not be 360 gallons per acre gross yield, but rather a mere 60 gallons per acre net yield, not even two fill-ups for an SUV. The entire state of Iowa, if planted in corn, would yield approximately five days of gasoline alternative.

To devote half the nation's corn crop to ethanol would require an input of 3.42 billion barrels of oil (almost half our current national use) to net 684 million barrels of "new" ethanol energy. We would also lose food and soil nutrients, suffer ecosystem damage, and use massive amounts of water for irrigation.

We need alternative energy. But ethanol from corn is neither scalable nor sustainable. Let's pursue better options.

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IN THEIR REPORT "ETHANOL CAN CONTRIBUTE to energy and environmental goals" (27 Jan., p. 506), A. E. Farrell *et al.* address the energy balance and greenhouse gas (GHG) emissions of ethanol from corn and show the pessimistic analysis of these issues by Pimentel and Patzek (*1*) to be wrong. Pimentel and Patzek are also wrong in their analysis of cellulose-derived ethanol.

Hammershlag's (*2*) estimates for the energy return per nonrenewable energy invested for near-term cellulosic ethanol technology range from 4.4:1 to 6.6:1, and Farrell *et al.* calculate a value of 8.3:1. The energy return for mature cellulosic ethanol technology is expected to be over 10:1 (*3*). Pimentel and Patzek estimate the energy return for cellulosic ethanol at 0.69:1. Why such a striking discrepancy? The primary reason is that Pimentel and Patzek estimate the externally supplied processing energy to be over 25 MJ/liter ethanol, whereas in all other studies this value is zero, since it is met by lignin from cellulosic biomass.

Whether energy return and greenhouse gas emissions of ethanol production are favorable depends on how the process is configured and designed. The fact that Pimentel and Patzek's