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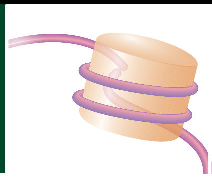

LETTERS

edited by Etta Kavanagh

Looking at Biofuels and Bioenergy

THE EDITORIAL "GETTING SERIOUS ABOUT BIOFUELS" (S. E. KOONIN, 27 JAN., P. 435) EMPHASIZES three important societal concerns that are addressed by a conversion to bioenergy: security of supply, lower greenhouse gas emissions, and support for agriculture.

We believe that bioenergy production and policies need to be based on a broad cost-and-benefit analysis at multiple scales and for the entire production chain. This is particularly true for bioenergy's impact on agriculture. One of the major problems in modern, intensive agriculture is the lost link between livestock and land (*1*). This separation between different agricultural production systems, environmental problems, and the consumers is largely unaccounted for in the development of economies and agricultural practices. Mitigation actions are needed to ensure global sustainability. It is possible that growth in bioenergy production (*2*) will add to these problems, reducing the overall benefits of conversion. A recent study on organic farming and bioenergy production (*3*) looked for solutions to such problems. Organic food production integrated with short rotation coppice and biogas utilization suggested a number of win-win solutions, for example, lower energy use per unit produced, water quality protection, recycling of nutrients, reduced nitrous oxide emissions, and increased soil carbon storage. Ecologically sound bioenergy production should aim for closed cycles of mass and optimization of net energy yields and efficiencies.

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YOUR RECENT ARTICLES ON BIOFUEL ("GETTING serious about biofuels," S. E. Koonin, Editorial, 27 Jan., p. 435; "The path forward for biofuels and biomaterials," A. J. Ragauskas *et al.*, Reviews, 27 Jan., p. 484; "Ethanol can contribute to energy and environmental goals," A. E. Farrell *et al.*, Reports, 27 Jan., p. 506) are arousing unreasonable expectations for its potential contribution to energy and environmental goals. Although biofuel's contribution can be positive, it will remain small, being restricted by the ability of the natural environment to provide both fuel and food for a large and energy-demanding world population.

It requires production equivalent to 0.5 ton of grain to feed one person for one year, a value sufficiently large to allow some production to be used as seed for the next crop, some to be fed to animals, and some land to be diverted to fruit and vegetable crops. Compare this value with that for a car running 20,000 km/year at an efficient consumption of 7 liters/100 km. The required 1400 liters of ethanol would be produced from 3.5 ton grain (2.48 kg grain/liter), requiring an agricultural production seven times the dietary requirement for one person.

Agriculture now provides, with some shortfalls, food for 6 billion people and will need to feed 9 billion by 2050, while conserving natural resources. From an agronomic perspective, increasing food production to this level during the next 50 years is an enormous challenge.

The above calculations demonstrate that major reliance on biofuel, even for private motoring alone, would place an additional demand on agricultural production greater than would providing an adequate diet for 9 billion people by 2050. Positive energy gain and reduced greenhouse gas emissions are not sufficient to establish biofuel as an economic and ecologically friendly solution to current problems of energy supply and ecological sustainability. Anything but a marginal contribution from biofuel would pose a serious threat to both food security and the natural resource base of land, soils, and water.

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Poplar

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I READ WITH INTEREST S. E. KOONIN'S EDITORIAL "Getting serious about biofuels" (27 Jan., p. 435) and applaud his support of alternative fuels. Unfortunately, his optimistic analysis provides the same shortsighted view of biomass production and resource sustainability that is driving the misdirected efforts of the ethanol industry today. Koonin's analysis does not address the environmental costs (specifically land degradation) of producing biofuels. He optimistically suggests that "with plausible technology developments, biofuels could supply some 30% of global demand in an environmentally responsible manner without affecting food production." Although encouraging, this type of logic includes flawed assumptions: (i) that biofuels will be produced "responsibly"; (ii) that food crop production and consumption will be sustained at current levels on existing footprints; and (iii) that the use of soil

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resources for production of transportation biofuels is ethical. As an illustration, the corn grain ethanol (the primary biofuel produced in the United States) that is produced on 3.5 million hectares of prime cropland (~12% of U.S. corn acreage on soils that are uniquely productive) yields less than 2% of our current fuel consumption. Year-round corn crops, encouraged by biofuel production, cause long-term soil degradation. This type of degradation cannot be repaired by fertilization, nor can fertilizer be used as "soil energy currency" in accounting for biofuel production costs. The real cost of this form of land use will not be realized by this or even the next generation, but will be borne by future generations who have no say in the energy policy of today. Biomass certainly has a place in our country's fuel mix, but in a nation that averages a paltry fuel economy of 20.8 miles/gallon, the production of relatively inefficient transportation fuels at the expense of soil resources and in the face of increasing global populations is irresponsible.

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Response

DALGAARD *ET AL.*, CONNOR AND MÍNGUEZ, AND DeLuca all raise important systems-level issues about biofuels. Their comments are well aligned with the principal point of the Editorial: Biofuels produced incidentally to food-crop agriculture are suboptimal in several dimensions, but the cellulose from engineered energy crops, processed in new ways, offers the prospect of significant improvement and material benefit for transport fuels. I agree that sustainability is an essential consideration as the system design space is being explored.

STEVEN E. KOONIN

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Measuring the Efficiency of Biomass Energy

IN A SOPHISTICATED JOURNAL SUCH AS *SCIENCE*, we expect the topic of energy policy to be illuminated by use of arithmetic and other analytical tools. The Review "The path forward for biofuels and biomaterials" (A. J. Ragauskas *et al.*, 27 Jan., p. 484) presents its most important datum, 10^{20} joules per year of sustainable biomass energy, without any attempt to relate it to energy consumption. The United States uses more than 400 million kilowatts of electrical power, or a little more than one kilowatt per capita. If we multiply this quantity by the number of seconds in a year (3600 × 24 × 365), the result is 1.26×10^{19} joules per year. Production of one unit of electrical energy requires three units of fuel energy; thus, the corresponding demand on biomass energy would be 0.38×10^{20} joules per year. For itself, the United States would use approximately 40% of the world's biomass energy just for electricity. The remainder of the energy, and more besides, would be consumed by transportation, space heating, and manufacturing. Nothing would be left over for the rest of the world. Because wind and solar energy have less potential than biomass energy, it is obvious that the global community must rely mainly on petroleum and coal.

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Response

WE AGREE WITH THE CORE POINT OF BROWER, that it would be foolish in the extreme to base energy needs solely on biomass or indeed any other source. The best security for energy provision will derive from the use of a range of technologies. For this very reason, our Review does not make claims for the "supremacy" of bioenergy. It is clear, however, that the use of biomass to supplement and replace oil for liquid transportation fuel will inevitably happen as oil supplies decline and become more costly. Our Review argues for the development of biorefinery technologies that optimally extract the greatest benefit from biomass resources. In addition, the form and flexibility of biofuels are advantages for transportation fuels.

Nevertheless, there are certain missed assumptions in Brower's figures. First, based on Parikka (*1*) and further on Kaltschmitt (*2*), who have used the International Energy Agency energy balance methods with physical energy content methodology, the current state of energy conversion efficiency is already included in the 100 EJ/year estimate, so the value does not need to be multiplied by three again. Second, Parikka reports the current sustainable biomass potential. This is the amount of biomass that is being produced but is underutilized throughout the world at present. Further gains could come from more efficiency, more productive land use, increased use of biomass wastes, etc. In addition, Perlack *et al.* (*3*) report current U.S. bioenergy where 190 million dry tons biomass become 2.9 Quads of bioenergy (a Quad is about 1 EJ); thus, the ultimate potential with improved production of 1.3 billion dry tons biomass might become 19 EJ/year electricity (even though transportation fuel appears a better use). Thus, the United States alone could meet an appreciable fraction of its domestic energy. Likewise, on a global scale, the World Energy Council and World Energy Assessment project that bioenergy could supply a maximum of 250 to 450 EJ/year (perhaps a quarter of global energy demand) by 2050.

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3. R. D. Perlack *et al., Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (U.S. Department of Energy and U.S. Department of Agriculture, April 2005; available at feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf).

Harvesting Our Meadows for Biofuel?

TWO PAPERS ("THE PATH FORWARD FOR BIOfuels and biomaterials," A. J. Ragauskas *et al.*, Reviews, p. 484; "Ethanol can contribute to energy and environmental goals," A. E. Farrell *et al.*, Reports, p. 506) and an Editorial ("Getting serious about biofuels," S. E. Koonin, p. 435) in the 27 January issue outline some of the promises of plant-derived ethanol for satisfying energy demands. Switchgrass (*Panicum virgatum*), which grows naturally throughout most of the continent, is a promising source material. The prospect of a native grass dominating an agricultural landscape is intriguing and potentially ecologically sound.

In nature, however, switchgrass almost invariably grows intermixed with other C_4 grasses such as bluestems. It is unclear whether vast monocultures of switchgrass can be sustainable, especially given that pathogen sources are likely to be present in natural populations of this species. It is also not clear whether these other C_4 grasses may be promising candidates for biofuels.

Biofuel engineers should consider the use of mixed-species, C_4-dominated grasslands as biofuel sources. This would not only avoid the potential instability of monocultures, but could help promote native biodiversity. In the southern Great Plains, vast areas of native tallgrass prairie are being lost due to the lack of fire (causing encroachment of woody plants) and due to development. Highly diverse native hay meadows, mowed annually, were once an important part of the landscape in Oklahoma but are now in serious decline.

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If we "bring back the meadows" and convert the harvest to fuel, we might simultaneously fill our gas tanks and conserve our natural heritage.

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Response

THE ANSWER TO THE QUESTION OF WHETHER monocultures will be used to produce bioenergy feedstocks depends on what it is you are trying to accomplish. Conventional wisdom suggests the following points:

i) There is every reason to believe that, at least from small-scale plots and some larger ones, we are receiving really good stand regeneration and yield per unit area from mixed stands of grasses (*1*).

ii) We have received some pretty strong indication from managers of Conservation Reserve Program (CRP) lands that mixed stands are appropriate for managing conservation acreage for purposes of soil stabilization, providing wildlife amenities, and improved seasonal stand proliferation and extended cover (*1*).

iii) We understand fairly well, at least at some relevant scale, the wildlife advantages of mixed grasses. Species populate the stands at different times of varying cover and find suitable nesting resources (*1*).

iv) We currently farm largely monocultures, especially in annual cropping scenarios, but we think that long-term perennial stands might be more productive, withstand disease or variation in climate and soils better, and use less water than a stand of a single or two species of switchgrass (*1*).

Finally, the biorefinery industry needs to think about the ramifications of farming perennial species as monocultures as opposed to mixed grass stands. Even planted acreage of trees for pulp and paper clearly demonstrates a kind of monoculture—loblolly pine and other pines in the southeast and hybrid poplar and hybrid willow in other areas. Some of the beetle infestation and forest fire risk ramifications are pretty demonstrative of the effects of closely spaced monocultures. There may be trade-offs in productivity, but ignoring the real substantive sustainability issues would be more costly.

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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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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.

NATHAN HAGENS, ROBERT COSTANZA, KENNETH MULDER

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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 process does not have positive energy returns should not be used to measure the potential of this promising energy path.

The science is clear; it's time to move on from the energy balance debate and focus on policies that encourage the greatest oil savings and reductions in greenhouse gas emissions from both corn and cellulosic ethanol.

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THE METHODOLOGICAL FLAWS IN A. E. FARRELL *et al.*'s Report "Ethanol can contribute to energy and environmental goals" (27 Jan., p. 506) are revealed in the authors' fig. 1b, which shows that motor gasoline has a negative net energy and the highest input/output ratio, while ethanol technologies have positive net energies and lower input/output ratios. These numbers imply that motor gasoline is the marginal fuel seeking to displace biomass fuels.

This contradiction is caused by inconsistencies in the boundaries that are used to analyze their energy balance. For motor gasoline, the authors add the energy content of the gasoline to the effort used to produce it. The energy used to produce motor gasoline is much less than its energy content —estimates for the total energy input/energy output ratio are about 0.06 (*1*).

For biomass fuels, the authors report only the petroleum input/output ratio. Other fuels used in the process should also be included; these cannot be assumed to be sustainable (as exemplified by natural gas shortages) The biomass fuels are not used as liquids—(much of the co-products are used to generate electricity), which also needs to be taken into account. Including these additional fuels raises the input/output ratio to 0.79 (ethanol today) or 0.82 (CO_2 intensive). If the U.S. economy used oil with an energy input/output ratio of about 0.8, the energy equivalent of about 80 million barrels per day of oil would be used to generate the 20 million barrels per day of refined petroleum products that the United States uses outside of the oil sector.

Once the boundaries are made equivalent, motor gasoline has a much higher energy surplus and a lower energy input/energy out ratio than biomass fuels. This result matches the economic reality described by the authors' first paragraph—biomass fuels, not motor gasoline, need subsidies and tax breaks.

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Reference

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IN THE NET-ENERGY ANALYSIS IN THEIR REPORT "Ethanol can contribute to energy and environmental goals" (27 Jan., p. 506), A. E. Farrell *et al.* do not (i) define the system boundaries, (ii) conserve mass, and, consequently, (iii) conserve energy. Most of the current First Law net-energy models of the industrial corn-ethanol cycle are based on nonphysical assumptions and should be discarded.

When properly formulated, mass and First Law energy balances of corn fields and ethanol refineries account for the photosynthetic energy, some of the environment restoration work, and the co-product energy (*1*). These show that production of ethanol from corn is two to four times less favorable than production of gasoline from petroleum. From thermodynamics, it also follows that the ecological devastation wrought by industrial biofuel production must be severe. With the DDGS coproduct energy credit, 3.9 gallons of ethanol displace on average the energy in 1 gallon of gasoline. Without the DDGS energy credit, this average number is 6.2 gallons of ethanol. Equivalent CO_2 emissions from the corn ethanol cycle are 50% higher than those from gasoline and become 100% higher if methane emissions from cows fed with DDGS are accounted for.

The U.S. ethanol industry has consistently inflated its ethanol yields by counting 5 volume percent of #14 gasoline denaturant (8% of energy) as ethanol. Also, imports from Brazil and longer chain alcohols seem to have been counted as U.S. ethanol (*1*). A detailed statistical analysis of 401 corn hybrids from Illinois reveals that the highest possible yield of ethanol is 2.64 ± 0.05 (SD) gallons EtOH/bu (*1*). The commonly accepted U.S. Department of Agriculture estimate of mean ethanol yield in the United States, 2.682 gallons EtOH/bu (*2*), is one standard deviation above this estimate.

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References and Notes

1. The detailed calculations and arguments can be found at http://petroleum.berkeley.edu/patzek/BiofuelQA/Materials/RealFuelCycles-Web.pdf.
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Response

WE THANK THE LETTER AUTHORS FOR THEIR comments. As Lynd *et al*. and Cleveland *et al.* point out, the potential benefits of cellulosic ethanol technologies would include a shift away from intensely farmed monocultures such as corn and positive effects on soil erosion, fertilizer runoff, and biodiversity. In addition, because cellulosic technologies can use a wide variety of feedstocks, their flexibility may allow for more applications worldwide. Similarly, we agree with Hagens *et al*. and Patzek that we need more sustainable processes than current corn ethanol production.

However, Hagens *et al*. are mistaken that our analysis excludes tractors or labor; these were included. And Cleveland *et al.* and Kaufmann incorrectly state that we ignored natural gas or coal inputs. These are explicitly included in the ERG Biofuels Analysis Meta-Model (EBAMM, cells N6, N28, N30, N37 and N38 in worksheet "Net Energy") (*1*).

We agree with Hagens *et al*., Cleveland *et al.*, and Patzek that meaningful measurement of environmental impacts is critical to an appropriate evaluation of biofuels. However, including incommensurable quantities such as soil erosion and climate change into a single metric requires an arbitrary determination of their relative value. We stressed the advantages of individual metrics for petroleum consumption and greenhouse gas emissions and encouraged the development of specific metrics for environmental effects such as soil erosion. In addition to exposing trade-offs among competing objectives, multiple metrics permit more focused analysis and help reduce uncertainty (see related correction on page 1748).

Hagens *et al*., Cleveland *et al.*, and Kaufmann incorrectly assert that our paper focused on energy return on investment (EROI). The Supporting Online Material explains why ratios such as EROI are methodologically inferior to the additive metric we use (*1*). Even a quality-adjusted EROI is a single metric that has the problems noted above. Furthermore, such aggregation can lead to mischaracterizations. For example, Hagens *et al.* inappropriately label total energy input into ethanol production as gasoline or petroleum, even though it is predominantly coal and natural gas.

Patzek's Letter is based on a non–peer-reviewed online document that has changed several times since its receipt. Nonetheless, much of his analysis appears to be rigorous in detail but erroneous overall. For instance, extractable starch only applies to wet milling, which presently produces approximately 30% of U.S. ethanol. Almost all new ethanol plants are dry mills, for which total fermentable starch is a better measure of ethanol yield, and that yield at least 5% more ethanol per unit mass of corn than wet milling (*2*, *3*). Further, Patzek arbitrarily assumes that spreading coproduct animal feed on agricultural land is the best way to maintain soil quality, ignoring among other things the potential of alternative cropping systems (*4*).

These Letters focus on different questions than did our paper. EROI measures the efficiency of primary energy production, but is not useful for comparing different ways of using fossil energy resources to create liquid transportation fuels, which was the point of our paper (*1*). Life-cycle assessments such as ours are not designed to balance mass and energy; they are designed to evaluate environmental implications of the production, use, and disposal of products and fuels.

In retrospect, we should have labeled our metric not as net energy value (NEV) but as Fossil Energy Value (FEV), which, following, is calculated as FEV = $E_{out} - (F_F + P_F)$, where E_{out} is the energy content in the delivered fuel, F_F is primary fossil energy in feedstocks, and P_F is the primary fossil input energy in nonfeedstocks (*5*). For biomass, F_F is zero, which explains the seeming inconsistency in system boundaries that Kaufmann reports (*2*). The system boundaries of EBAMM are clearly defined in Equations S-1 through S-7, even if not explicitly labeled as such.

Like the Letter authors, we believe that ethanol can contribute to energy and environmental goals only as part of an overall strategy that also includes more efficient vehicles, other sustainable energy sources, and careful monitoring of ethanol production. The magnitude and timing of this contribution will depend on the development of better methods of producing ethanol than today's corn-based approach. To encourage these changes, we should measure what we care about—greenhouse gas emissions and soil erosion, for example—and provide strong incentives to ethanol producers to improve their performance in these areas. A close reading of our paper and supporting material reveals far more agreement among us all than these Letters suggest.

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Caution on Nominee to Head USGS

IN THE NEWSMAKERS ITEM "NEW USGS HEAD" (19 May, p. 995) on the nomination of Mark Myers to head the U.S. Geological Survey (USGS), I was quoted by the writer Erik Stokstad as saying that Myers "has a significant amount of integrity." I have no direct knowledge of Myers and therefore have no basis for evaluating his fitness for the job. However, his background is in such contrast to previous USGS directors that I said to Stokstad that Congress must ask some very tough questions of Myers before confirming him.

As I said to Stokstad, because of the Bush Administration's history of interfering with the integrity of science conducted at agencies and of being overly friendly to the oil and gas industry, Congress should demand full answers from Myers regarding his view on the independence of the government's main science agency and whether he would stand up to an administration that has shown no qualms about dismissing good science when it conflicts with political goals.

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CORRECTIONS AND CLARIFICATIONS

News of the Week: "Court revives Georgia sticker case" by C. Holden (2 June, p. 1292). The article incorrectly characterizes the Discovery Institute in Seattle, Washington, as a think tank for the creationist movement. The institute is a public policy organization that operates many different programs, including the Center for Science & Culture, which supports the work of scholars who explore challenges to evolution and promote the concept of intelligent design.

News of the Week: "RU-486–linked deaths open debate about risky bacteria" by J. Couzin (19 May, p. 986). The story mistakenly implied that a woman's risk of death from a *Clostridium sordellii* infection after a nonsurgical abortion is about 1 in 100,000. In fact, this is the estimated risk of contracting a *C. sordellii* infection following a nonsurgical abortion; to date, the infections are invariably fatal.

Reports: "Ethanol can contribute to energy and environmental goals" by A. E. Farrell *et al.* (27 Jan. 2006, p. 506). Michael Wang of Argonne National Laboratory has raised interesting and important issues associated with greenhouse gas (GHG) emissions from corn (maize) ethanol production in this Report. The U.S. Department of Agriculture (USDA) confirmed that the data reported for lime application had been calculated incorrectly and kindly updated these values. The custom report and an updated version of the Supporting Online Material that discusses the issues raised in this erratum in more detail are downloadable from http://rael.berkeley.edu/EBAMM. The corrected data are expected to be available on the USDA Web site in the coming months. In conducting a reanalysis, even larger uncertainties were discovered in the emissions factor of lime and the emission factor for nitrous oxide (N_2O) resulting from nitrogen fertilizer application. With these refinements, the *Ethanol Today* case now yields a point estimate of net greenhouse gases for corn ethanol at 18% below conventional gasoline, very close to the initially reported value of 15% below gasoline, but with an expanded uncertainty band of –36% to +29%.

TECHNICAL COMMENT ABSTRACTS

Comment on "Nature of Phosphorus Limitation in the Ultraoligotrophic Eastern Mediterranean"

Michelle S. Hale and Richard B. Rivkin

Thingstad *et al*. (Reports, 12 August 2005, p. 1068) reported that in situ mesoscale phosphorus enrichment of the eastern Mediterranean Sea altered selected biological parameters and concluded that the added phosphorus was rapidly transferred from bacteria to mesozooplankton. However, because of a lack of replication and a misinterpretation of their statistical analyses, that conclusion is not supported by the data.

Full text at www.sciencemag.org/cgi/content/full/312/5781/1748c

Response to Comment on "Nature of Phosphorus Limitation in the Ultraoligotrophic Eastern Mediterranean"

T. F. Thingstad, C. S. Law, M. D. Krom, R. F. C. Mantoura, P. Pitta, S. Psarra, F. Rassoulzadegan, T. Tanaka, P. Wassmann, C. Wexels Riser, T. Zohary

With no requirement for synoptic treated (IN) and control (OUT) stations, analysis of covariance is an interesting statistical technique for testing IN-OUT differences in Lagrangian experiments, but it has inherent limitations due to its assumption of linear responses. With this limitation properly considered, we find that analysis of covariance strengthens, not weakens, experimental support for the food-web transfer mechanisms we proposed.

Full text at www.sciencemag.org/cgi/content/full/312/5781/1748d

Letters to the Editor

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