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zFacts on ethanol

See yellow highlights on the following page(s).

Fact: **It takes 0.8 GGE of energy to produce 1 GGE of corn ethanol.**
Fact: **Production and use of ethanol save 12% of GHGs.**

Source: "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels." Proceedings of the National Academy of Science, July 25, 2006 | vol. 103 | no. 30 | 11206-11210. (Google this title to find complete document.)

Notes:

Net Energy Balance:
From the Abstract: Ethanol's NEB = 1.25. One unit of energy in gives 1.25 of energy out as ethanol. Divide input and output by 1.25 to find that 0.8 in gives 1.0 out.

GHG Savings:
First page: The production and combustion of ethanol saves 12% on GHGs (uses 88%) compared to gasoline. See also next page.

Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels

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Contributed by David Tilman, June 2, 2006

Negative environmental consequences of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation biofuels. To be a viable alternative, a biofuel should provide a net energy gain, have environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies. We use these criteria to evaluate, through life-cycle accounting, ethanol from corn grain and biodiesel from soybeans. Ethanol yields 25% more energy than the energy invested in its production, whereas biodiesel yields 93% more. Compared with ethanol, biodiesel releases just 1.0%, 8.3%, and 13% of the agricultural nitrogen, phosphorus, and pesticide pollutants, respectively, per net energy gain. Relative to the fossil fuels they displace, greenhouse gas emissions are reduced 12% by the production and combustion of ethanol and 41% by biodiesel. Biodiesel also releases less air pollutants per net energy gain than ethanol. These advantages of biodiesel over ethanol come from lower agricultural inputs and more efficient conversion of feedstocks to fuel. Neither biofuel can replace much petroleum without impacting food supplies. Even dedicating all U.S. corn and soybean production to biofuels would meet only 12% of gasoline demand and 6% of diesel demand. Until recent increases in petroleum prices, high production costs made biofuels unprofitable without subsidies. Biodiesel provides sufficient environmental advantages to merit subsidy. Transportation biofuels such as synfuel hydrocarbons or cellulosic ethanol, if produced from low-input biomass grown on agriculturally marginal land or from waste biomass, could provide much greater supplies and environmental benefits than food-based biofuels.

corn | soybean | life-cycle accounting | agriculture | fossil fuel

High energy prices, increasing energy imports, concerns about petroleum supplies, and greater recognition of the environmental consequences of fossil fuels have driven interest in transportation biofuels. Determining whether alternative fuels provide benefits over the fossil fuels they displace requires thorough accounting of the direct and indirect inputs and outputs for their full production and use life cycles. Here we determine the net societal benefits of corn grain (*Zea mays* ssp. *mays*) ethanol and soybean (*Glycine max*) biodiesel, the two predominant U.S. alternative transportation fuels, relative to gasoline and diesel, the fossil fuels they displace in the market. We do so by using current, well supported public data on farm yields, commodity and fuel prices, farm energy and agrichemical inputs, production plant efficiencies, coproduct production, greenhouse gas (GHG) emissions, and other environmental effects.

To be a viable substitute for a fossil fuel, an alternative fuel should not only have superior environmental benefits over the fossil fuel it displaces, be economically competitive with it, and be producible in sufficient quantities to make a meaningful impact on energy demands, but it should also provide a net energy gain over the energy sources used to produce it. We therefore analyze each biofuel industry, including farms and production facilities, as though it were an "island economy" that is a net energy exporter only if the energy value of the biofuel and its coproducts exceeds that of all direct and indirect energy inputs (see Tables 1–6 and *Supporting Text*, which are published as supporting information on the PNAS web site).

Biofuel production requires energy to grow crops and convert them to biofuels. We estimate farm energy use for producing corn and soybeans, including energy use for growing the hybrid or varietal seed planted to produce the crop, powering farm machinery, producing farm machinery and buildings, producing fertilizers and pesticides, and sustaining farmers and their households. We also estimate the energy used in converting crops to biofuels, including energy use in transporting the crops to biofuel production facilities, building and operating biofuel production facilities, and sustaining production facility workers and their households. Outputs of biofuel production include the biofuels themselves and any simultaneously generated coproducts. For purposes of energy accounting, we assign the biofuels themselves an energy content equal to their available energy upon combustion. Coproducts, such as distillers' dry grain with solubles (DDGS) from corn and soybean meal and glycerol from soybeans, are typically not combusted directly; rather, we assign them energy equivalent values.

Results

Net Energy Balance (NEB). Despite our use of expansive system boundaries for energy inputs, our analyses show that both corn grain ethanol and soybean biodiesel production result in positive NEBs (i.e., biofuel energy content exceeds fossil fuel energy inputs) (Fig. 1; see also Tables 7 and 8, which are published as supporting information on the PNAS web site), which reinforce recent findings (1–5). Although these earlier reports did not account for all of the energy inputs included in our analyses, recent advances in crop yields and biofuel production efficiencies, which are reflected in our analyses, have essentially offset the effects of the broad boundaries for energy accounting that we have used. Our results counter the assertion that expanding system boundaries to include energetic costs of producing farm machinery and processing facilities causes negative NEB values for both biofuels (6–8). In short, we find no support for the assertion that either biofuel requires more energy to make than it yields. However, the NEB for corn grain ethanol is small, providing ≈25% more energy than required for its production. Almost all of this NEB is attributable to the energy credit for its DDGS coproduct, which is animal feed, rather than to the ethanol itself containing more energy than used in its production. Corn grain ethanol has a low NEB because of the high energy input required to produce corn and to convert it into ethanol. In contrast, soybean biodiesel provides ≈93% more energy than is required in its production. The NEB advantage of

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Conflict of interest statement: No conflicts declared.

Abbreviations: NEB, net energy balance; GHG, greenhouse gas; EEL, energy equivalent liter; DDGS, distillers' dry grain with solubles.

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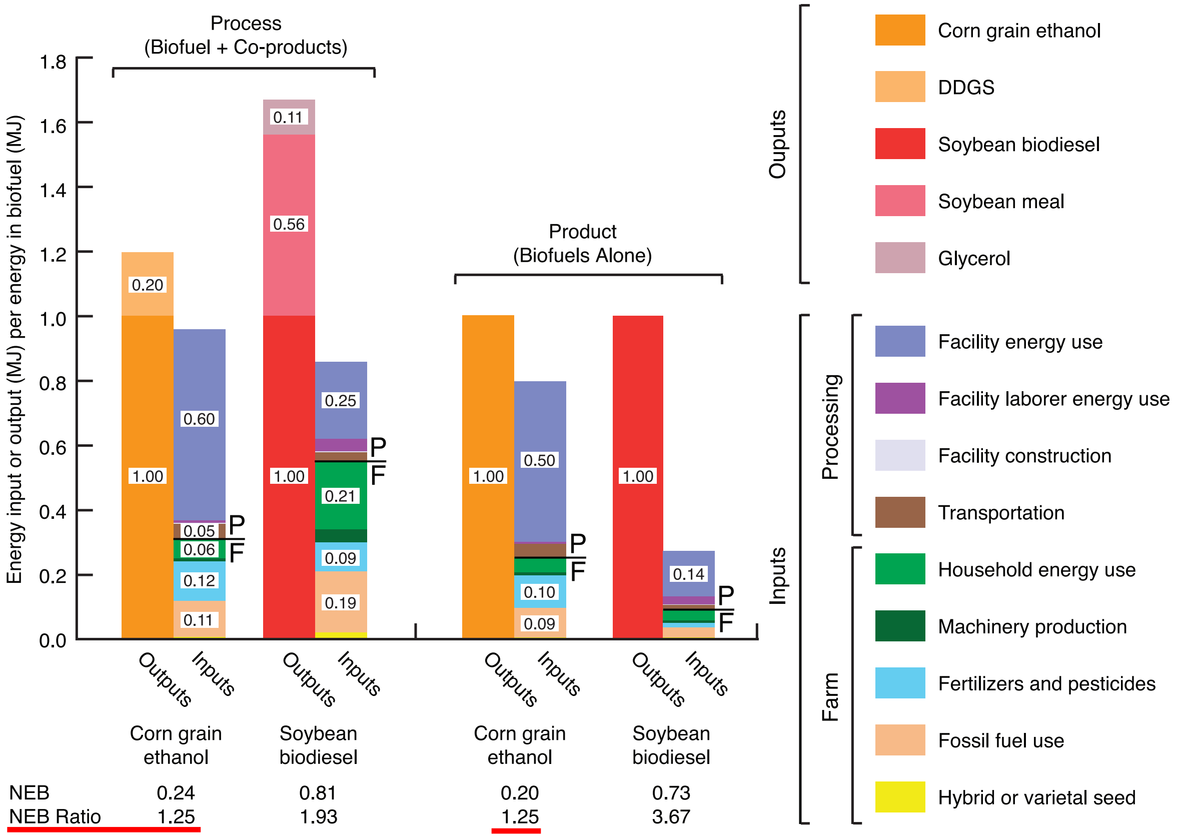

Fig. 1. NEB of corn grain ethanol and soybean biodiesel production. Energy inputs and outputs are expressed per unit energy of the biofuel. All nine input categories are consistently ordered in each set of inputs, as in the legend, but some are so small as to be nearly imperceptible. Individual inputs and outputs of ≥ 0.05 are labeled; values < 0.05 can be found in Tables 7 and 8. The NEB (energy output − energy input) and NEB ratio (energy output/energy input) of each biofuel are presented both for the entire production process (*Left*) and for the biofuel only (i.e., after excluding coproduct energy credits and energy allocated to coproduct production) (*Right*).

soybean biodiesel is robust, occurring for five different methods of accounting for the energy credits of coproducts (see Table 9, which is published as supporting information on the PNAS web site).

Life-Cycle Environmental Effects. Both corn and soybean production have negative environmental impacts through movement of agrichemicals, especially nitrogen (N), phosphorus (P), and pesticides from farms to other habitats and aquifers (9). Agricultural N and P are transported by leaching and surface flow to surface, ground, and coastal waters causing eutrophication, loss of biodiversity, and elevated nitrate and nitrite in drinking-water wells (9, 10). Pesticides can move by similar processes. Data on agrichemical inputs for corn and soybeans and on efficiencies of net energy production from each feedstock reveal, after partitioning these inputs between the energy product and coproducts, that biodiesel uses, per unit of energy gained, only 1.0% of the N, 8.3% of the P, and 13% of the pesticide (by weight) used for corn grain ethanol (Fig. 2*a*; see also Table 10, which is published as supporting information on the PNAS web site). The markedly greater releases of N, P, and pesticides from corn, per unit of energy gain, have substantial environmental consequences, including being a major source of the N inputs leading to the "dead zone" in the Gulf of Mexico (11) and to nitrate, nitrite, and pesticide residues in well water. Moreover, pesticides used in corn production tend to be more environmentally harmful and persistent than those used to grow soybeans (Fig. 2*b* and Table 10). Although blending ethanol with gasoline at low levels as an oxygenate can lower emissions of carbon monoxide (CO), volatile organic compounds (VOC), and particulate matter with an aerodynamic diameter $\leq 10\ \mu m$ (PM10) upon combustion, total life-cycle emissions of five major air pollutants [CO, VOC, PM10, oxides of sulfur (SO_x), and oxides of nitrogen (NO_x)] are higher with the "E85" corn grain ethanol–gasoline blend than with gasoline per unit of energy released upon combustion (12). Conversely, low levels of biodiesel blended into diesel reduce emissions of VOC, CO, PM10, and SO_x during combustion, and biodiesel blends show reduced life-cycle emissions for three of these pollutants (CO, PM10, and SO_x) relative to diesel (5).

If CO_2 from fossil fuel combustion was the only GHG considered, a biofuel with NEB > 1 should reduce GHG emissions because the CO_2 released upon combustion of the fuel had been removed from the atmosphere by plants, and less CO_2 than this amount had been released when producing the biofuel. However, N fertilization and incorporation of plant biomass into soil can cause microbially mediated production and release of N_2O, which is a potent GHG (13). Our analyses (see Table 11, which is published as supporting information on the PNAS web site) suggest that, because of the low NEB of corn grain ethanol, production and use of corn grain ethanol releases 88% of the net GHG emissions of production and combustion of an energetically equivalent amount of gasoline (Fig. 2*c*). This result is comparable with a recent study that estimated this parameter at 87% using different methods of analysis (1). In contrast, we find that life-cycle GHG emissions of soybean biodiesel are 59% those of diesel fuel. It is important to note that these estimates assume these biofuels are derived from crops harvested from land already in production; converting intact ecosystems to production would result in reduced GHG savings or even net GHG release from biofuel production.