*Increased dependence on ethanol would place the United States at the mercy of a highly volatile energy source.*

# Neither Renewable Nor Reliable

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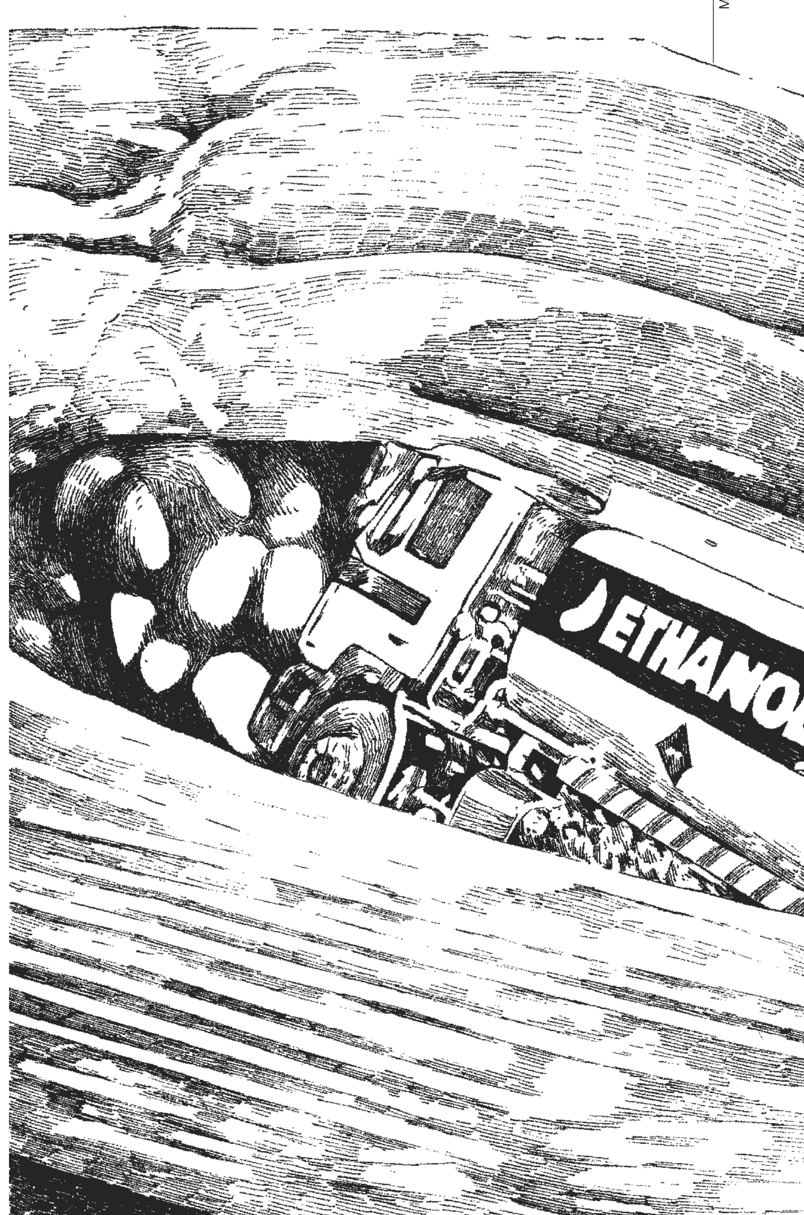


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Until recently, the process of producing ethanol was widely believed to use more energy than it created. But farming and ethanol conversion practices have improved, and ethanol proponents now argue that it is a sustainable and more secure alternative to gasoline. For instance, a particularly optimistic study conducted by the U.S. Department of Agriculture — one widely cited by ethanol proponents — estimates that for every unit of energy used to produce ethanol from corn, 1.34 units are created.

Many politicians have embraced the notion that ethanol is a renewable, sustainable energy source. President Bush, after signing the Energy Policy Act of 2005 that included a generous increase in the subsidies to ethanol producers, said, "The bill includes a flexible, cost-effective renewable fuel standard that will double the amount of ethanol and biodiesel in our fuel supply over the next seven years." More recently, a bipartisan group of Midwestern senators introduced a bill entitled "The BioFuels Security Act" that, as part of a new "renewable fuels standard," calls for the production of 227 billion liters of ethanol and biodiesel by the year 2030.

Clearly, the promise of a renewable automobile fuel is a major driving force behind support for ethanol. Nonetheless, there has been little or no discussion of how much gasoline could be displaced if ethanol were produced in a sustainable fashion. Furthermore, though reliability is obviously a central component of an energy security policy, policymakers and researchers have

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paid little attention to the likelihood of an ethanol supply disruption relative to that of petroleum.

## IS ETHANOL SUSTAINABLE?

If the objective of promoting ethanol is to rely more on domestic energy sources, then perhaps it would be more efficient to use natural gas and liquefied coal to power cars. Vehicles compatible with those energy sources have been operating on U.S. roadways for years, and reliance on those fuels would not disrupt the food supply. If, however, the objective of U.S. ethanol policy is to power cars with a sustainable, domestically produced fuel — the objective publicly promoted by the U.S. government — then the modeling approach used to analyze the policy should assume ethanol is produced in a sustainable fashion.

A simple way to do this is to create a balanced energy model where a portion of the ethanol output is fed back into the production and distribution process to make up for the energy used to farm, distill, and transport the ethanol. It is important to note that this approach is not meant to be literal; for example, ethanol would not typically be burned locally at distillation plants to power the process. Nonetheless, this approach simplifies the traditional analysis that mixes renewable and fossil fuel sources, which makes judging the relative merit of ethanol as a renewable energy source ambiguous. Therefore, in our analysis below, we convert energy contribution from fossil fuel sources to equivalent amounts of ethanol, and subtract the ethanol from the gross production values.

Virtually all ethanol produced in the United States comes from corn. Farmers grow the corn that converts solar energy into chemical energy. Then, the harvested corn is transported to a distillation plant where it is converted into ethanol. Finally, the ethanol is trucked to fueling stations.

*Table 1*

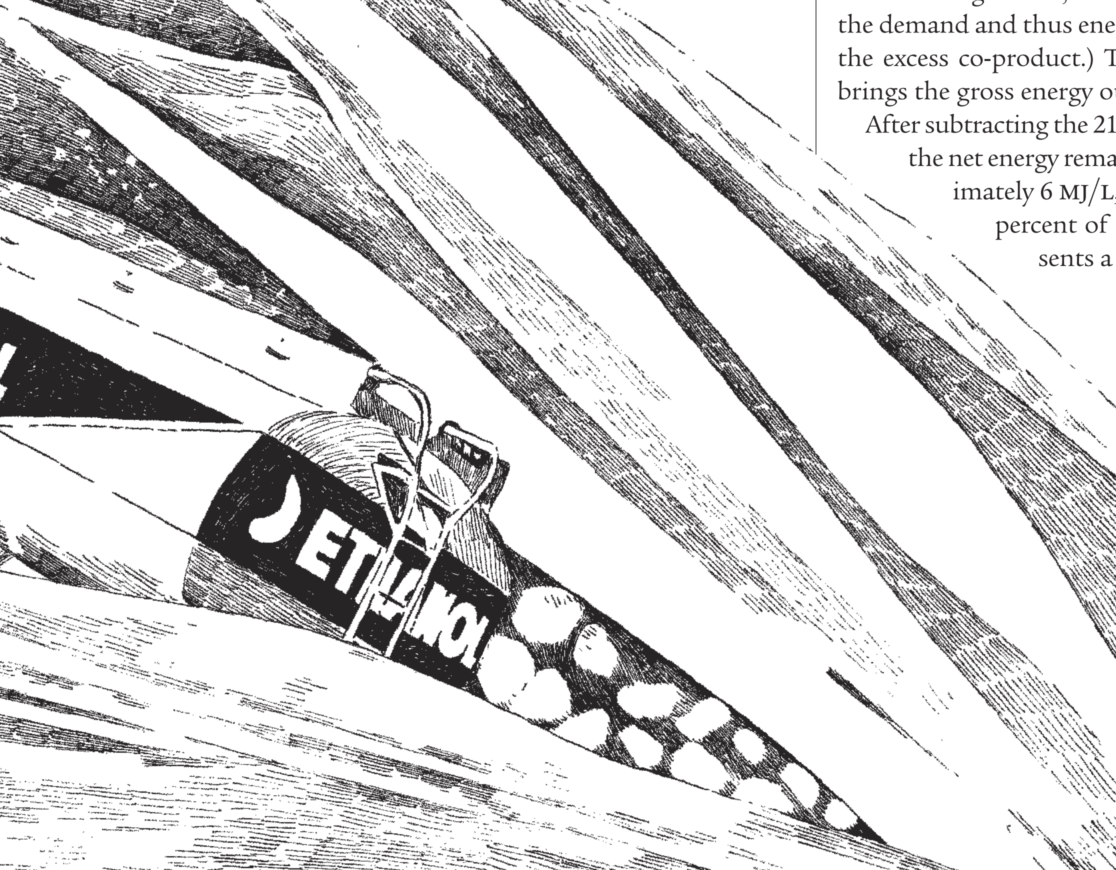
### Ethanol's Net Energy

USDA estimate of the net energy gained from producing one liter of corn ethanol

| | MJ/L |
|---|---|
| Energy in one liter of ethanol | 23.6 |
| USDA credit | 3.8 |
| Grow corn | (6.0) |
| Transport corn to distillation plant | (0.6) |
| Operate distillation plant | (14.4) |
| Transport ethanol to fueling stations | (0.4) |
| **Net energy** | **6.0** |

Table 1 shows the USDA's estimate of the energy required at each stage of this process to produce one liter of ethanol. In particular, approximately 6.0 megajoules per liter (MJ/L) are required at the corn-growing stage, 0.6 MJ/L are required to transport the corn to the ethanol plant, 14.4 MJ/L are required to operate the ethanol plant, and 0.4 MJ/L are required to truck the ethanol to fueling stations. A liter of ethanol contains approximately 23.6 MJ of energy.

The USDA study adds an "energy credit" of about 3.8 MJ to account for energy contained in co-products. The logic behind the energy credit is that co-products (mostly feed for cattle) have economic value and would require energy to produce if they were not produced during the ethanol process. (In establishing this credit, the USDA ignores the fact that if enough ethanol were produced to actually displace significant amounts of gasoline, the supply of co-product would exceed the demand and thus energy would be required to dispose of the excess co-product.) The inclusion of this energy credit brings the gross energy output of ethanol to near 27.4 MJ/L. After subtracting the 21.4 MJ required to power this process, the net energy remaining for automobile fuel is approximately 6 MJ/L, which, in essence, means that 25.6 percent of each liter of ethanol created represents a net energy gain.



**ENOUGH CORN?** Using the net energy yield reported in Table 1, we can calculate how much corn would be required to displace 15 percent of U.S. gasoline consumption. The estimate requires some assumptions regarding how much corn the United States can produce. We assume that the number of metric tons of corn harvested per hectare is 9,400, equal to the 2006 average (which was a record-setting yield). Further, we assume the number of hectares harvested is approximately 30.4 million, which equals the 2005 harvest (the second-largest on record). Those assumptions imply a total harvest of 28.45 million metric tons. Finally, consistent with the USDA study, we assume that a metric ton of corn produces 4,000 liters of ethanol.

Based on the Bureau of Transportation Statistics, 15 percent of our annual gasoline consumption is over 98.6 billion liters. Since, according to the Department of Energy, flex-fuel vehicles typically get about 20–30 percent fewer miles per liter when fueled with the ethanol-gasoline blend E85, this means that a minimum of 123.3 billion liters of ethanol would be required to replace 15 percent of U.S. gasoline consumption.

According to the USDA study, the net energy (including the offsetting energy credit for cattle feed) used to farm, distill, and transport one liter of ethanol is near 17.6 MJ. A liter of ethanol provides a heating value of about 23.6 MJ, so we will need to withhold 0.744 liters of ethanol to cover the production energy for every full liter produced. That leaves a net gain of 0.256 liters for sale to the customer.

*Table 2*

## Reliability

Summary statistics for the annual percentage change in corn yields and oil imports

| | Mean | Standard Deviation | 90% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Corn Yields | 3.3 | 11.9 | -31.8 | 38.6 |
| Petroleum Imports | 5.0 | 6.7 | -14.9 | 24.9 |

not expected to keep up with food demand.

Researchers predict that even under the best-case global warming scenario, corn yields are likely to decline by 22 percent in the short-run. What is more worrisome for an energy security policy that would rely to some extent on a reliable supply of corn is that researchers believe U.S. corn-yield variability is escalating, and the most productive farmers face a higher risk for catastrophic losses because of increased sensitivity to weather conditions.

**If we devoted all corn grown in the United States to sustainable ethanol production, we could displace only about 3.5 percent of current gasoline consumption.**

The USDA study assumes the ethanol plant can yield 10.14 liters of ethanol for every bushel of corn. This converts to a yield of 2.5 kg/L where one bushel of corn weighs 25 kg. Since only 25.6 percent of each liter of ethanol represents the energy gain, the United States will need to produce 9.77 kg of corn for every liter sold to the customer. Or inverting this, we will net 0.103 liters of ethanol for every kilogram of corn harvested. Consequently, 1,203 million tons of corn, or over 423 percent of the all-time high harvest, would be needed in order for ethanol to displace 15 percent of U.S. gasoline consumption. If we devoted 100 percent of all corn grown in the United States to producing ethanol, we could displace only about 3.5 percent of current gasoline consumption.

### IS ETHANOL RELIABLE?

Data from the National Agricultural Statistics Service show that since 1960, total corn harvests have increased from about 102 to 267 billion kg. Over the same period, the total number of squared meters harvested has fluctuated around 275 billion, meaning that production gains are almost entirely explained by yield increases, not changes in the agricultural footprint. However, researchers have observed that the year-to-year percentage gain in yields has steadily declined over the same period. The rate peaked at 3–5 percent in the early 1960s and was less than 1.5 percent in 2001 — a growth rate that is

The point of this discussion is to emphasize that there is little reason to expect corn-yield variability to decline. If we assume it will stay constant, we can use historical data to estimate what sorts of ethanol disruptions we can expect in the future. We can then compare corn-yield variability to variability in oil imports to see which is more reliable. The period we consider is 1960–2005, a period that included, among other oil shocks, the Six-Day War, the Arab oil embargo, the Iranian revolution, and the outbreak of the Iran-Iraq War.

The first step in determining which energy source is more reliable is to identify which distribution best fits the empirical data so we can calculate the standard deviation — a common measure of variability. Using observations for the annual change in corn production and oil imports, we use the Kolmogorov-Smirnov test to rank the fit of alternative distributions. Table 2 reports the results. The distribution that best fits the corn data is the logistic with mean 3.3 percent and a standard deviation of 11.9 percent. The distribution that best fits the oil data is a logistic with mean 5 percent and a standard deviation of 6.8 percent. The 90 percent confidence intervals suggest that in one out of every 20 years, we can expect corn yields to decline by 31.8 percent, while we can expect oil imports to decline by 14.9 percent. Thus, based on history, by displacing gasoline with ethanol we exchange geo-political risk with yield risk, and history suggests that yield risk is about twice as high.

**SUPPLY RESPONSE** Relying on ethanol exposes the economy to an entirely new risk — an undesirable link between ethanol supply disruptions and ethanol demand shocks created by their joint dependency on weather. In the case of gasoline, there is no obvious link. For example, during a particularly hot and dry summer the demand and price for gasoline increases as we drive longer distances to escape the heat, spend more time on congested roads, and use our air conditioning more often. But the hot weather does not increase the cost of producing gasoline, so increases in the price of gas have an unambiguously positive impact on the supply of gas.

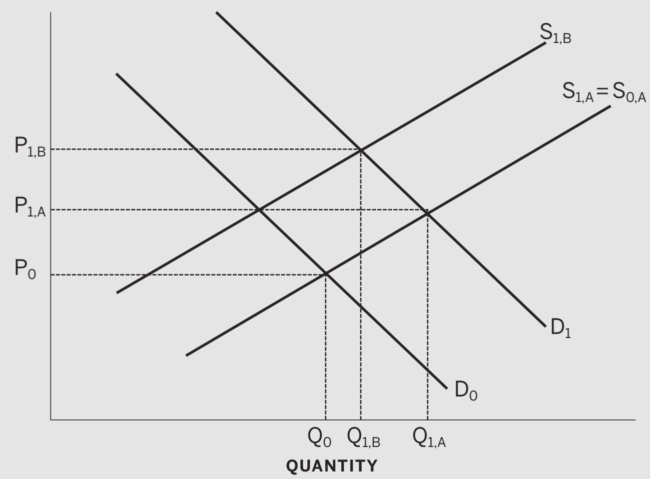
The relationship is illustrated in Figure 1. $D_0$ and $S_{1,A}$ are, respectively, the demand and supply curves for gasoline. The two curves conceptually illustrate that the demand for gasoline decreases and the supply of it increases as price increases and vice versa. The intersection of the two curves indicates the price where producers are willing to supply the same quantity that is demanded — the market equilibrium. Suppose $Q_0$ and $P_0$ are the equilibrium quantity and price of gasoline, respectively, before, say, a heat wave. In response to a heat wave, the demand for gasoline shifts outward to $D_1$. The market supply curve, which depends on the marginal cost of producing gasoline, does not shift because the marginal cost is not affected by the heat wave. The result is the new equilibrium ($P_{1,A}$, $Q_{1,A}$). In the case of ethanol, as with gasoline, a heat wave shifts the demand curve out to $D_1$. But, because corn yields are especially sensitive to rainfall shortages during July and high-temperatures during August, the heat wave also shifts the supply curve back as lower corn yields, or increased input costs, increase the marginal cost of producing ethanol.

The result of the correlation between demand shocks and supply shortages is to weaken the supply response relative to that of gasoline. For example, a supply-curve shift to $S_{1,B}$ increases the equilibrium price, relative to the case where marginal costs are not affected by weather, from $P_{1,A}$ to $P_{1,B}$ and reduces the equilibrium quantity from $Q_{1,A}$ to $Q_{1,B}$. The actual strength of the weather-created link between fuel demand shocks and the price of corn is unknown, but the relationship should be well understood before framing an energy security policy around ethanol.

*Figure 1*

### Weather Shock

An illustration of an ethanol and gasoline market equilibrium following a weather shock




## CONCLUSION

When we assume the ethanol production process is fully renewable, it would take all the corn in the country to displace about 3.5 percent of our gasoline consumption — only slightly more than we could displace by making sure drivers' tires are inflated properly. There are also ethical considerations. In particular, the United States is responsible for over 40 percent of the world's corn supply and 70 percent of total global exports. Even small diversions of corn supplies to ethanol could have dramatic implications for the world's poor, especially considering that researchers believe that food production will need to triple by the year 2050 to accommodate expected demand. Furthermore, ethanol would not necessarily be a more reliable source of fuel. By displacing gasoline with ethanol, we are displacing geo-political risk with yield risk, and historical corn yields have been about twice as volatile as oil imports. Finally, because high temperatures can simultaneously increase fuel demand and the cost of growing corn, the supply response of ethanol producers to temperature-induced demand shocks would likely be weaker than that of gasoline producers. **R**

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