The Debate is Over: Ethanol is a Net Energy Winner

There is now a strong consensus among scientists: the energy output from burning ethanol as a fuel source exceeds the energy input required for ethanol production. Studies that suggest that corn ethanol has a negative net energy balance rely on outdated data, and fail to consider coproduct generation and other factors that improve ethanol's energy efficiency. Furthermore, the energy balance of corn ethanol is steadily increasing as corn farmers and ethanol producers embrace new technologies.

1. Scientific evidence shows that ethanol has a positive net energy balance, while petroleum is a clear energy loser.

In June 2004, the U.S. Department of Agriculture updated its 2002 analysis of ethanol production and determined that the net energy balance of ethanol production is 1.67 to 1.[1] For every 100 BTUs of energy used to make ethanol, 167 BTUs of ethanol is produced. In 2002, USDA had concluded that the ratio was 1.35 to 1. The USDA findings have been confirmed by additional studies conducted by the University of Nebraska and Argonne National Laboratory. These figures take into account the energy required to plant, grow and harvest the corn—as well as the energy required to manufacture and distribute the ethanol.

Ethanol opponents frequently cite studies by Cornell University's Dr. David Pimentel and Tad W. Padzek, who concluded that ethanol returns only about 70% of the energy used in its production (a net energy balance of -29%). Pimentel's findings have been consistently refuted by USDA and other scientists who say his methodology uses obsolete data and is fundamentally unsound. In a detailed analysis of Pimentel's research, Dr. Michael S. Graboski of Colorado School of Mines says Pimentel's findings are based on out-of-date statistics (22 year-old data) and are contradicted by USDA.[2] Pimentel's reports have also been debunked by Michael Wang and Dan Santini of the Center for Transportation Research, Argonne National Laboratory, who conducted a series of detailed analyses on energy and emission impacts of corn ethanol from 1997 through 1999.[3] A recent study by UC scientists, published in the January, 2006 edition of *Science* magazine, also acknowledges a positive net energy balance for ethanol, placing the energy return at between 4 and 9 MJ/L.[4]

Furthermore, even the most pessimistic assessments of ethanol's energy balance acknowledge that ethanol is an improvement over petroleum-based fuels. Using the same analytical methods employed by some ethanol critics, Michigan State University's Bruce Dale calculates the net energy of petroleum to be -45%, compared to the -29% that Pimentel and Patzek find for ethanol. In the worst-case scenario, burning ethanol is still more energy-efficient than burning gasoline.[5]

"Unfortunately, his (Pimentel's) assessment lacked timeliness in that it relied on data appropriate to conditions in the 1970's and early 1980s, but clearly not the 1990s…With up-to-date information on corn farming and ethanol production and treating ethanol co-products fairly, we have concluded that corn-based ethanol now has a positive energy balance of about 20,000 BTU per gallon."

- Michael Wang and Dan Santini

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[1] http://www.ethanolrfa.org/objects/documents/files/net_energy_balance_2004.pdf
[2] http://www.ncga.com/ethanol/pdfs/EthanolfFuelsRebuttal.pdf
[3] http://www.ethanolrfa.org/objects/documents/80/31961.pdf
[4] Alexander E. Farrel, et al, "Ethanol Can Contribute to Environmental and Policy Goals," *Science* 311, January 2006, http://www.eere.energy.gov/afdc/pdfs/estreviewofethanollca.pdf.
[5] Bruce E. Dale, "Thinking Clearly About Biofuels: Ending the Silly Net Energy Controversy," 05 February 2007.

Excepting Pimentel & Patzek, the values of [corn ethanol's return on energy investment] range from 1.29 to 1.65 for current technology, indicating that corn ethanol is returning at least some renewable energy on its fossil energy investment. Pimentel & Patzek's result of [return on investment] <1 is an exception

- Hammerschlag, "Ethanol's Energy Return on Investment: A Survey of the Literature, 1990 – Present," in Environmental Science and Technology 40:6 (2006).

Two of the studies stand out from the others because they report negative net energy values and imply relatively high GHG emissions and petroleum inputs…these two studies also stand apart from the others by incorrectly assuming that ethanol coproducts…should not be credited with any of the input energy and by including some input data that are old and unrepresentative of current processes, or so poorly documented that their quality cannot be evaluated

- Farrell, et al, "Ethanol Can Contribute to Energy and Environmental Goals," in Science 311 (January 2006).

Dr. Pimentel's corn yield statistics date from 1992, meaning that the study does not take into account recent advances in the efficiency of corn growing. Corn yields have increased by over 10% since then with significantly lower inputs such as fertilizer, pesticides, etc., per bushel… Dr. Pimentel's figures for energy used in the ethanol conversion process date from 1979. Today's ethanol plants use far less energy per gallon of ethanol produced.

- Environmental and Energy Study Institute, October 2003

Pimentel & Patzek's results [for the energy balance of cellulosic ethanol production] stand out, at nearly an order of magnitude larger values for nonrenewable energy inputs than the other three studies. The reason for the difference is that Pimentel & Patzek assume that industrial process energy is generated by fossil fuel combustion and electricity, rather than by lignin combustion. All well-developed models of cellulosic production generate industrial energy with lignin combustion. The other three research teams, all of whom assume this, are highly credible

- Hammerschlag, "Ethanol's Energy Return on Investment: A Survey of the Literature, 1990 – Present," in Environmental Science and Technology 40:6 (2006).

"Patzek worked for Shell Oil Company as a researcher, consultant and expert witness. He founded and directs the UC Oil Consortium, which is mainly funded by the oil industry at the rate of $60,000 to $120,000 per company per year."

-www.journeytoforever.org/ethanol_energy.html

"The finished liquid fuel energy yield for fossil fuel dedicated to the production of ethanol is 1.34, but only 0.74 for gasoline. In other words, the energy yield of ethanol is (1.34/.74) or 81 percent greater than the comparable yield for gasoline."

- Minnesota Department of Agriculture

"The available energy from ethanol is much higher than the input energy for producing ethanol. In other words, using ethanol as a liquid transportation fuel would significantly reduce domestic use of petroleum even in the worst case scenario."

- Michigan State University

Corn ethanol is energy efficient…Moreover, producing ethanol from domestic corn stocks achieves a net gain in a more desirable form of energy. Ethanol production utilizes abundant domestic energy supplies of coal and natural gas to convert corn into a premium liquid fuel that can replace petroleum imports by a factor of 7 to 1.

- Shapouri, Duffield, and Graboski, "Estimating the Net Energy Balance of Corn Ethanol," 1995

Even the most pessimistic estimate of corn ethanol's [return on energy investment] (Pimentel & Patzek at…0.84) is higher than the [return on investment] for gasoline, so it seems safe to say that corn ethanol reduces fossil fuel consumption when used to displace gasoline.

- Hammerschlag, "Ethanol's Energy Return on Investment: A Survey of the Literature,

1990 – Present," in Environmental Science and Technology 40:6 (2006).

2. Coproduct utilization, plant location, and business strategy all make a difference in determining an ethanol plant's net energy balance.

Energy from ethanol is not the only result of ethanol production. Coproducts, such as distillers' grains, gluten feed, carbon dioxide and corn sweeteners, are also created in ethanol production. This means that not all of the energy used by an ethanol plant is directed at manufacturing ethanol, and the energy output from ethanol combustion is not the only positive factor to be considered in determining the net energy balance of the ethanol production process. Because distillers grains can be burned as an energy source, there may even be opportunities for the plant to be self-powered or to export energy, resulting in an energy return of over 100%.

Ethanol producers can enhance the energy payoff from coproduct utilization by making smart business decisions. For example, some ethanol production facilities are strategically located adjacent to cattle feeders and dairies. These sites enable local marketing of distillers' grains, thus avoiding energy intensive drying processes and reducing fuel use for transportation. As a result, these processes use significantly less energy than the industry standard, and can reduce greenhouse gas emissions by up to 40 percent compared to conventional gasoline.

…net energy calculations are most sensitive to assumptions about coproduct allocation. Coproducts of ethanol have positive economic value and displace competing products that require energy to make. Therefore, increases in corn ethanol production…will lead to more coproducts that displace whole corn and soybean meal in animal feed, and the energy saved thereby will partly offset the energy required for ethanol production

- Farrell, et al, "Ethanol Can Contribute to Energy and Environmental Goals," in Science 311 (January 2006).

The production of ethanol comes with a range of byproducts, such as distillers dried grains with soluble (DDGS) in the dry milling operation, and corn gluten feed (CGF), corn gluten meal (CGM), and corn oil in the wet milling process. The energy used to produce corn and convert corn to ethanol… should be allocated to ethanol and byproducts.

- Shapouri, Duffield, and Graboski, "Estimating the Net Energy Balance of Corn Ethanol," 1995

"Studies that reported negative net energy incorrectly ignored coproducts and used some obsolete data."

- Farrell, et.al, Science, January 27, 2006

When coproduct energy credits are added to the calculations, the NEV of corn ethanol is positive regardless of the type of milling used. Dry-milling results in the highest NEV, 19,290 Btu, but wet-milling NEV differs by only 4,989 Btu per gallon. The NEV for weighted average case is 16,193 Btu per gallon. Adjusting for coproduct credits also increases the energy ratio significantly. The energy ratio is 1.21, and 1.30 for wet- and dry-milling, respectively, and the weighted average energy ratio is 1.24.

- Shapouri, Duffield, and Graboski, "Estimating the Net Energy Balance of Corn Ethanol," 1995

The distillers grains complex represents valuable coproducts of ethanol production from corn grain. Distillers grains can provide from 35 to 40% of the total diet for feedlot cattle…With increased ethanol production, more coproducts may be generated than cattle feedlots and dairies can use. If this situation occurs, coproducts can be burned as energy sources for ethanol plant operation or exported to foreign markets.

- Cassman, et al, "Convergence of Agriculture and Energy: Implications for Research and Policy," College of Agricultural Science and Technology, November 2006.

Dry mills have some potential to drop their gross energy input by offering an undried coproduct…this is…economically viable if the coproduct does not need to be transported long distances.

- Hammerschlag, "Ethanol's Energy Return on Investment: A Survey of the Literature, 1990 – Present," in Environmental Science and Technology 40:6 (2006).

…the energy requirements for drying coproducts for transport as DDGS represents roughly one-third the total energy used in a typical ethanol plant. Thus, a trend toward using WDGS [wet distillers' grains] as cattle feed is emerging because of the lower energy requirements…Transportation costs are a critical factor in considering plant location. In addition to optimizing plant location, a move toward "closed loop" ethanol plants is feasible. In this scenario, cattle are fed larger volumes of the coproducts, and cattle waste products and excess coproducts are used as fuel sources to replace a portion of the natural gas used to power the biorefinery.

- Cassman, et al, "Convergence of Agriculture and Energy: Implications for Research and Policy," College of Agricultural Science and Technology, November 2006.

3. New innovations and technologies are constantly improving the energy balance for ethanol production.

The net energy balance of ethanol production continues to improve as ethanol production becomes more efficient. One bushel of corn now yields 2.8 gallons of ethanol—up from 2.5 gallons just a few years ago. Today's ethanol plants produce 15 percent more ethanol from a bushel of corn—and use 20 percent less energy in the process – than those of five years ago.

The energy efficiency of American farmers is also contributing to improvements in the energy efficiency of ethanol production. According to USDA statistics, U.S. agriculture uses about half the energy to produce a unit of output today than in 1950. Better corn varieties, improved production practices and conservation measures also figure into the equation. A one percent increase in corn yield raises the net energy value of ethanol by 0.37 percent.[6]

The future for ethanol is even brighter. Ethanol derived from cellulosic sources will offer even greater energy savings and greenhouse gas reductions. Not only are the energy inputs to grow cellulosic biomass relatively minimal, but cellulosic feedstocks will generate energy to power ethanol plants as a coproduct of production, and may even reduce energy consumption as compared to gasoline by more than 100 percent by generating excess energy to export to the power grid.[7]

Today's higher corn yields, lower energy use per unit of output in the fertilizer industry, and advances in fuel conversion technologies have greatly enhanced the economic and technical feasibility of producing ethanol compared with just a decade ago. Studies using older data may tend to overestimate energy use because the efficiency of growing corn and converting it to ethanol has improved significantly over the past 10 years. The net energy value (NEV) of corn ethanol was calculated as 16,193 Btu/gal when fertilizers are produced by modern processing plants, corn is converted in modern ethanol facilities, farmers achieve normal corn yields, and energy credits are allocated to coproducts.

- Shapouri, Duffield, and Graboski, "Estimating the Net Energy Balance of Corn Ethanol," 1995

Corn yield plays a critical role in determining the energy balance of starch-based ethanol. In fact, a 1 percent increase in corn yield raises NEV by 0.37 percent. Importantly, with the exception of a few bad years, corn yields have been increasing over time since 1975. This means that farm resources are being used much more efficiently because less energy (fossil fuel) is being put into the growing process, while more ethanol is being produced.

- Environmental and Energy Study Institute, October 2003

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[6] http://www.eesi.org/programs/Agriculture/Energy%20Balance%20update.htm
[7] http://www.oregon.gov/ENERGY/RENEW/Biomass/docs/FORUM/EthanolEnergyBalance.pdf

A key factor in determining the net impact of ethanol use on GHG emissions is the overall energy efficiency of the grain-to-ethanol-and-coproduct utilization life cycle. For example, nitrogen fertilizer alone represents about one-half of all energy input to rain-fed corn production because nitrogen fertilizer production requires large fossil fuel energy input. In addition, the use of nitrogen fertilizer results in the release of nitrous oxide, a potent GHG…improvement in nitrogen fertilizer efficiency leads directly to increased energy efficiency and a decrease in GHG emissions...Fortunately, U.S. corn producers are steadily improving nitrogen fertilizer efficiency

- Cassman, et al, "Convergence of Agriculture and Energy: Implications for Research and Policy," College of Agricultural Science and Technology, November 2006.

According to USDA, fertilizer accounts for about 45% of the energy required to grow corn. However, the use of fertilizer in grain production, which includes chemical inputs such as nitrogen, potash and phosphate, has been in general decline since the early 1980's. 3 In the years from 1985-2000, nitrogen used per planted acre of corn declined from 140 lbs. to 132 lbs; phosphate from 60 lbs. to 47 lbs. per acre; and potash from 84 lbs. to 51 lbs. per acre. The most significant of these decreases is nitrogen, as "it has a much higher average energy requirement than phosphorous and potash fertilizers."

- *Environmental and Energy Study Institute, October 2003*

…cellulosic ethanol plants incorporate an integrated power plant that uses the lignin in the feedstock to generate electricity and heat for process energy. Because most of the energy requirements associated with cellulosic ethanol production are derived from renewable sources, the conversion process uses virtually no fossil fuels. A 1999 ANL report (Wang 1999) estimated that cellulosic ethanol can reduce fossil energy consumption relative to gasoline by 88 to more than 100 percent, depending on the type of feedstock. Reductions of fossil energy by more than100 percent come from a co-product credit for the sale of excess electricity from cellulosic ethanol plants.

- *Andress, "Ethanol Energy Balances," report prepared for the US Department of Energy, November 2002*

Cellulosic ethanol has a net energy balance of over 60,000 Btu per gallon, largely due to the fact that little fossil energy is used in biomass farming and cellulosic ethanol conversion… cellulosic ethanol plants will presumably produce "extra" energy that can be fed into the power grid. Doing so will effectively displace the use of electricity produced in power plants, which for the most part rely upon fossil fuels.

- *Environmental and Energy Study Institute, October 2003*

4. Ultimately, achieving a positive net energy is less important than achieving the bottom-line goals of ethanol production: reducing our contribution to climate change and our reliance on foreign oil.

When it comes to the benefits of ethanol production, energy balance alone doesn't tell the entire story. Energy used to produce ethanol represents an investment in displacing nonrenewable fuels with renewable alternatives – whereas energy used to produce gasoline, for example, goes toward perpetuating the problems associated with petroleum-based fuel sources. Comparisons between ethanol and gasoline, or between any two fuel sources, are meaningless unless the important implications of petroleum substitution are considered.

For every barrel of crude oil that enters the refining process, about 0.85 barrel of liquid fuel reaches the market as gasoline. By contrast, investing a barrel's worth of petroleum to generate energy for ethanol production yields about 20 barrels of energy-equivalent liquid fuel. Thus, by switching from gasoline to ethanol, we can extend our supplies of petroleum and reduce our reliance on foreign oil.[8] Additionally, an April, 2007 report from the Environmental Protection Agency found that life-cycle greenhouse gas emissions from corn

[8] http://www.ncga.com/ethanol/pdfs/020607ThinkingClearlyAboutBiofuels.pdf

ethanol are 21.8 percent lower than those from gasoline.[9] In order to make responsible use of our energy resources, we need to calculate our return on investment not only in terms of energy in versus energy out, but also in terms of improvements in our long-term energy and climate security. Using those metrics, ethanol is a clear winner.

The increased use of renewable and alternative fuels can result in significant reductions in the use of petroleum-based fuels. By displacing petroleum fuels, many, although not all, of these fuels can provide reductions in greenhouse gas emissions.

- EPA, "Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use," April 2007

One barrel of oil yields approximately 0.85 barrels of liquid fuels (gasoline, diesel, etc) when refined. It also requires about 0.1 additional "barrels of oil equivalent" in the form of both coal and natural gas to discover, produce, refine and distribute gasoline and diesel, etc. In contrast, one barrel of petroleum "invested" to produce corn ethanol will give us about 20 barrels of liquid fuel on an equivalent energy basis—greatly extending supplies of petroleum. Cellulosic ethanol has similar numbers and these values will improve as technology improves.

Different energy carriers cannot be compared on straight energy basis. In the real world, the different "qualities" of different energy carriers must be considered.

If we are to make wise decisions as we embark on this brave new world of alternative fuels, we will need to carefully choose our metrics of comparison. We want attractively priced alternative fuels that will reduce total petroleum use and also provide environmental improvements versus gasoline and diesel. These are appropriate metrics for biofuels and other alternatives.

- Bruce E. Dale, Professor of Chemical Engineering, Michigan State University, February 2007

FURTHER READING

For background on this and other ethanol issues, please consult the following sources:

Renewable Fuels Association energy balance resources:
http://www.ethanolrfa.org/resource/reports/#Balance

United States Department of Energy:
http://www.eere.energy.gov/afdc/altfuel/eth_energy_bal.html

Report on ethanol's energy balance by UC Berkeley scientists (2005):
http://rael.berkeley.edu/EBAMM/

United States Department of Agriculture: http://www.usda.gov/oce/reports/energy/index.htm

Survey of energy balance studies published in *Science*, 2006:
http://www.eere.energy.gov/afdc/pdfs/estreviewofethanollca.pdf

UC Study on the California Low-Carbon Fuels Standard:
http://www.arb.ca.gov/fuels/lcfs/ucstudyfinal.pdf

[9] http://www.epa.gov/otaq/renewablefuels/420f07035.htm