Issue Brief:

Net Energy Balance of Ethanol Production

Spring 2009 A Publication of Ethanol Across America

Study after study after study confirms that ethanol production from corn produces more energy than it takes to make it, period. End of story. So why is this still an issue? When you look at the facts, it simply isn't.

Energy. You need it to push, pull, lift or otherwise move something. From gasoline to power an automobile to a gentle breeze that moves a leaf to the carbs in a breakfast bar that get you going in the morning—it's all energy.

The energy industry has traditionally gauged energy in terms of its ability to heat something, with the resulting heat causing movement. That value has been measured in BTUs, or British Thermal Units, which, among other things, provided at least some ability to compare apples and oranges. It allows one to begin the process of determining if a ton of coal is a better choice than a ton of wood to run a boiler. In a perfect world that would be easy. Depending on cost, if it took two tons of wood to run your boiler for one hour and only one ton of coal, you'd opt for coal. Or would you?

Maybe you would ask questions such as: Where does it come from? What does it take to make it? What are the environmental impacts? What form is it in? What other values or debits need to be considered? These very questions are the basis for the Argonne National Laboratory's GREET model. GREET stands for **G**reenhouse gases, **R**egulated **E**missions and **E**nergy use in **T**ransportation. *(See sidebar on page 3)*

Detractors of ethanol have argued for thirty years that ethanol production is not an efficient means of reducing petroleum use. While fundamentally incorrect, this assertion has been at the forefront of the public policy debate over expanded ethanol use. Typically, those fuels being displaced by ethanol would revert back to the BTU count. Criticism of ethanol comes down to this: It takes more BTUs to make it than it provides.

The comparison has always seemed straightforward and simple. Because a gallon of ethanol is similar in size, weight and application to a gallon of gasoline, people fell into the easy trap of comparing the BTUs in a gallon of ethanol to a gallon of gas—found it to be lower—and declared "case closed."

Inside

Dear Friends:

On behalf of our fellow board members of the Ethanol Across America education campaign, we are very pleased to bring you this update of our very first in the highly successful Issue Brief series of publications.

Originally released in 2004, this brief on *The Net Energy Balance of Ethanol Production*, produced in cooperation with the U.S. Department of Agriculture, once again clearly demonstrates that the production of fuel grade ethanol yields significantly more energy than is used in its production. This includes the growing and harvesting of crops, transportation, and other considerations. Interestingly we did not need to substantially revise this document as the data of several years ago that showed a positive energy balance has only gotten better. Today's ethanol plants are using 20% less energy than just four years ago!

Critics of biofuels have long raised this issue of net energy but it misses the point. The use of total energy is not always the optimum means of assessing the value of biofuels. The challenge facing this nation is primarily the need for transportation fuels. Using energy in one form to produce another form that is more useful will almost always entail a conversion penalty. Gasoline from oil, electricity from coal, and most other forms of energy are prime examples. Even with losses in most forms of energy, ethanol reverses that trend and as we continue to develop a range of biofuels it will only get better. Using non-feed grains and waste products will turn our next generation of fuels into biorefineries and literally into factories where we manufacture energy.

We welcome thoughtful discussion of these issues and believe the **Ethanol Across America** education campaign is increasing the awareness and understanding of the public, the media, and policy makers.

Sincerely,

Tim Johnson	Lee Terry
US Senate	US House of Representatives

The reality is far less straightforward—and comparisons based on raw numbers are indeed comparing apples to oranges. There are too many economic, social and practical factors that need to be considered for anyone to put a pencil to the back of an envelope to determine that one form of energy is better than another. One must look at the situation with respect to what ethanol is replacing and what it is achieving.

Energy balance does not mean energy benefits. We are trying to reduce fossil energy use for many obvious reasons. Ethanol from corn and cellulosic biomass uses substantially less petroleum than it takes to make gasoline to drive your car. The result is fuel that truly reduces greenhouse gases and provides a wide range of economic and social benefits. This is why the GREET model is important in providing a more complete picture.

In addition to simply over-counting the energy used in producing ethanol, detractors fail to recognize the significant gains of recent years in yields and energy used in processing. Modern ethanol plants are producing more ethanol from a bushel of corn and using less energy to do so.

Early arguments by ethanol detractors were based on outdated models of ethanol production that relied on 1930's era plants that produced industrial and beverage alcohol using oil as a primary process fuel. Other ethanol opponents simply distorted energy balance studies by intentionally using outdated information related to energy inputs associated with processing ethanol produced from grain. The reality is that the ethanol industry has steadily increased its output while decreasing the energy used.

To be fair, it is important to look at the energy used to make energy. What is unfair is the refusal by detractors to apply realistic, practical assumptions so that we can make more informed judgments.

Fuels and Electricity		
BTU Content (LHV):		
Diesel fuel	128,450	per gallon
Gasoline	116,090	per gallon
LPG	84,950	per gallon
Natural gas	983	per cubic ft.
Electricity	3,412	per kwh
Coal	9,773	per pound
Ethanol	76,330	per gallon

Source: USDA

Low heat value in different types of energy and fuels.

For example, it is unfair to attribute all the energy used to grow a bushel of corn and process it into its value as an energy product (i.e. ethanol). Ethanol production is a co-product of corn processing and therefore should only be charged with the energy that was used to turn it into ethanol. In addition, the nature of agricultural commodities is that they are rarely grown for a specific purpose. That bushel would be grown and processed into feed as a matter of course. Corn is

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Introduction of the GREET and ASPEN PLUS® Models

While we have tried to employ a common sense approach to looking at energy balance, the exercise remains at heart a function of modeling and spreadsheets. We have referenced the GREET and ASPEN models, both of which are critical to the USDA studies.

Since 1995, with funding from the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy, Argonne National Laboratory has been developing the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model.

The model is intended to serve as an analytical tool for use by researchers and practitioners in estimating fuel-cycle energy use and emissions associated with new transportation fuels and advanced vehicle technologies. Argonne released the first version of the GREET model — GREET 1.0 — in June 1996. Since then, Argonne has released a series of GREET versions with revisions, updates, and upgrades.

The most recent GREET version is GREET 1.6, which, together with GREET documentation, is posted at Argonne's GREET Web site (http://greet.anl.gov). The GREET model is in the public domain and free of charge to use. Users can download the GREET model from its Web site. At present, there are more than 1,200 registered GREET users in North America, Europe, and Asia representing governmental agencies, universities, research institutions, automotive industry and energy industry.

For a given transportation fuel/technology combination, the GREET model separately calculates:

1. Fuel-cycle energy consumption for
   a) Total energy (all energy sources),
   b) Fossil fuels (petroleum, natural gas, and coal), and
   c) Petroleum;

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Independent Observers Look at Energy Balance Studies

Ethanol critics such as Cornell University's Dr. David Pimentel, who argue that ethanol production uses more energy than it yields, are consistently at odds with all other studies on ethanol's energy balance. Since 2004 there have been several studies that have analyzed the various inputs of producing ethanol from corn as well as accounting for greenhouse gases.

In February of 2006 the Natural Resources Defense Council (NRDC) and Climate Solutions issued a report, *Ethanol: Energy Well Spent, A Survey of Studies Published Since 1990.* The NRDC and Climate Solutions study reviewed the six most prominent studies on energy balance for ethanol that were published since 1990: Marland and Turhollow (1991), Lorenz and Morris (1995), Grabowski (2002), Shapouri et al. (2002), Pimentel and Patzek (2005), and Kim and Dale (2005). All but the Pimentel and Patzek study showed renewable returns on non-renewable energy investment for corn ethanol. Renewable energy returns ranged from 1.29 to1.65. The NRDC Climate Solutions report details the higher energy inputs that were used by Pimentel and Patzek in their research that resulted in the significantly lower energy returns. NRDC / Climate Solutions concluded that the Pimentel and Patzek study was an "outlier" and that corn ethanol's energy balance does indeed contribute to reduced fossil energy use and oil imports.

In another assessment, The University of California at Berkeley deconstructed the six major studies on ethanol's energy balance and then re-ran the analysis after correcting errors in the studies or updating data. The goal of the UC Berkeley analysis was to understand how six studies on the energy balance for corn ethanol could come to such different conclusions. In addition to looking at energy balance, the study also looked at the environmental impacts, such as the production of greenhouse gases.

Ethanol's Net Energy Value:A Summary of Major Studies

Authors and Date	NEV (Btu)
Shapouri, et. al, (1995)	+20,436 (LHV)
Lorenz and Morris (1995) - Institute for Local Self-Reliance	+30,589 (LHV)
Agri. and Agri-Food, CAN (1999)	+29,826 (LHV)
Wang, et. al. (1999) – Argonne National Laboratory	+22,500 (LHV)
Pimentel and Patzak (2005)	-22,119 (LHV)
Shapouri, et. al, Update (2002) – USDA	+21,105 (LHV)
Kim and Dale (2002)	+23,866 to +35,463 (LHV)
Shapouri, et. al, (2004) – USDA	+30,258 (LHV)

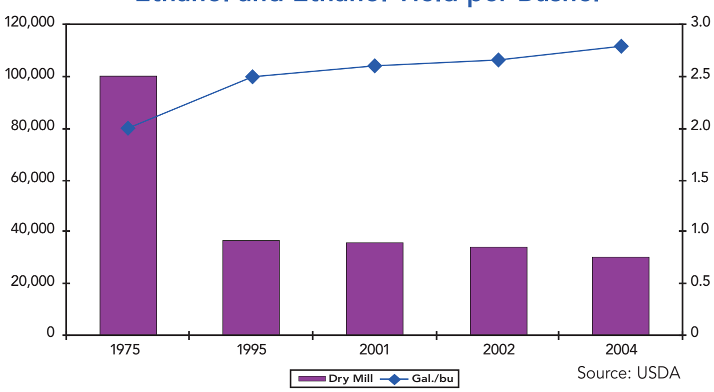
According to the University of California Berkley analysis, once they had made the changes in the assumptions underlying the models, they found that all six studies came to the same conclusion: that it is better to use fossil energy inputs to grow corn and make ethanol than to use gasoline directly in automobiles. The analysis was supported by the Energy Foundation, The National Science Foundation's Climate Decision-Making Center at Carnegie Mellon University and the Karsten Family Foundation.

A third study was done by the Laboratory for Energy and the Environment at Massachusetts Institute of Technology. The MIT study was called Review of Corn Based Ethanol Energy Use and Greenhouse Gas Emissions. The MIT study, which was done in 2006, concluded that on average it takes 0.03 gallons of oil to produce 1 gallon of ethanol. Although the energy content of a gallon of ethanol is only about 70% of that of gasoline, the study concluded that each gallon of ethanol replaces .67 gallons of petroleum, a significant petroleum reduction. The report indicated that very little petroleum is used in ethanol production, which is dominated by natural gas.

grown as a result of overall demand and sold into broad markets. Of course there is energy used in growing corn; the issue is to allocate that energy use in a fair and balanced way.

The rub seems to come when the BTU counters start adding on everything they can think of that is even remotely related to the ethanol process. Sure, it's reasonable to count the energy used to transport corn to a processing plant. But is it reasonable to attribute all the energy used to make the steel that made the truck doing the hauling? Some detractors would have you believe so.

Dry-Mill: Thermal Energy Use per Gallon of Ethanol and Ethanol Yield per Bushel



Source: USDA

The definition of net energy value (NEV) is the difference between the energy in the fuel product (output energy) and the energy needed to produce the product (input energy). In the 1980's it was thought that the ethanol energy balance was neutral to negative: The amount of energy that went into producing ethanol was equal to or greater than the energy contained in the ethanol. Since then the advances in the farming community, as well as technological advances in the production of ethanol, have led to positive returns in the energy balance of ethanol.

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"Introduction of the GREET and ASPEN PLUS® Models"
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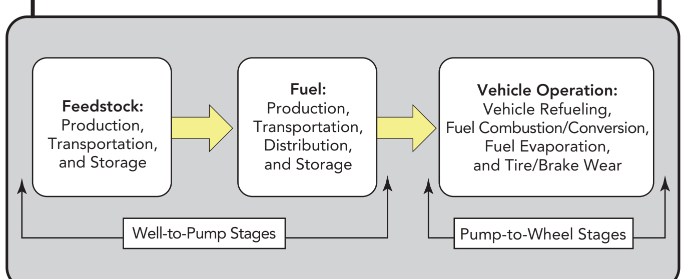
2. Fuel-cycle emissions of greenhouse gases
   a) Carbon dioxide (CO_2) (with a global warming potential [GWP] of 1),
   b) Methane (CH_4) (with a GWP of 23), and
   c) Nitrous oxide (N_2O) (with a GWP of 296);

3. Fuel-cycle emissions of five criteria pollutants (separated into total and urban emissions)
   a) Volatile organic compounds (VOCs),
   b) Carbon monoxide (CO),
   c) Nitrogen oxides (NOx),
   d) Particulate matter with a diameter measuring 10 micrometers or less (PM10), and
   e) Sulfur oxides (SOx).

The figure below presents stages and activities covered in GREET simulations of fuel cycles. A fuel-cycle analysis (also called a well-to-wheels analysis) includes the feedstock, fuel, and vehicle operation stages. The feedstock and fuel stages together are called well-to-pump (also upstream) stages, and the vehicle operation stage is called the pump-to-wheel (also downstream) stage. In GREET, fuel-cycle energy and emission results are presented separately for each of the three stages.



Stages Covered in GREET Fuel-Cycle Analysis

GREET includes these vehicle technologies: spark ignition engines, compression ignition engines, spark ignition engine hybrid vehicles, compression ignition hybrid vehicles, fuel-cell vehicles, and battery-powered

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As recently as 2005 two contrasting studies, Pimentel and Patzek, and Shapouri, et. al, used average ethanol plant yield of 2.5 and 2.64 gallons respectively of ethanol yield per bushel of corn. In a 2007 survey done for the Renewable Fuels Association, average ethanol yield was reported to have increased to 2.74 gallons per bushel for wet mills and 2.81 for dry mills.

Since the average wet mill processes about 3 times as much corn as a dry mill, a conservative estimate of current yield would still be 2.76 gallons per bushel. This conservative estimate of 2.76 gallons of ethanol per bushel of corn ethanol is 9.6% higher than what is reported by Pimentel and 3.8% increase over USDA estimates. This increase is due to continuing process changes in plants and improved enzymes and yeasts.

In a statement before the Committee on Energy and Natural Resources in June 2008, Assistant Secretary for Energy Efficiency and Renewable Energy Alexander Karsner stated "Today's corn-based ethanol has a positive energy balance – that is, the energy content of ethanol is greater than the fossil energy used to produce it – and this balance is constantly improving with new technologies."

Ethanol from Cellulose: Supersize My Energy Gains

As we have shown with overwhelming evidence, ethanol produced from corn results in a net energy gain. The key factor in making this determination is the energy input, which is primarily due to energy expended in growing the corn. Even with that energy there is a net gain.

But what if you could make ethanol from products with little or no energy inputs?

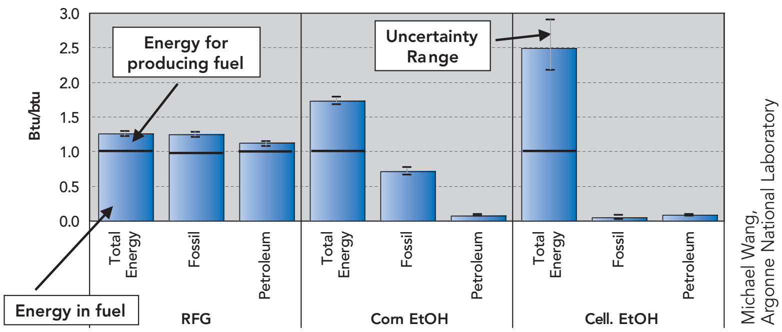
Products such as municipal waste; specialty energy crops, such as switchgrass or fast growing woody poplars; or forestry and agricultural residues; food processing wastes and assorted yard and green wastes. Products that all have a minimum energy input, yet can be attractive feedstocks for ethanol offering yields competitive with feed-grains. At that point the energy savings become dramatic.

Much as one tracks the BTU trail in assessing overall energy inputs, the greenhouse gas impact of these ethanol feedstocks is extremely attractive.

General Motors certainly thinks so. In 2001 General Motors commissioned a study to assess the "well-to-wheel" impact of a variety of traditional and alternative fuels in an effort to assess their complete lifecycle, energy consumption, and greenhouse gas emissions. That study compared 15 propulsion technologies and 75 different fuel pathways.

The results were that ethanol reduces greenhouse gas emissions compared to conventional gasoline. Ten percent blends using corn-derived ethanol provided a 20 percent reduction, while biomass-derived ethanol would result in a near 100 percent reduction.

Energy Benefits of Fuel Ethanol Lie in Fossil Energy and Petroleum Use



Energy Use for Each BTU of Fuel Used

In 2007 the Center for Transportation Research at Argonne National Laboratory analyzed the efficiency of US ethanol plants. The analysis was based on survey results of the energy used in current ethanol facilities. Survey results indicated that total energy use for fossil energy and electricity decreased by 21.8% in dry mills and 7.2% in wet mills from 2001 survey data.

And it keeps getting better:

Energy consumption in ethanol plants has been on a steady and remarkable decline. As the ethanol industry has grown, efficiency has increased dramatically. Modern ethanol plants are spaced age compared to the first generation plants and this must be kept in mind when understanding the true net energy of ethanol.

"Introduction of the GREET and ASPEN PLUS® Models"
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electric vehicles. GREET includes these transportation fuels: gasoline, diesel, methanol, compressed natural gas, liquefied petroleum gas, liquefied natural gas, ethanol, biodiesel, hydrogen, Fischer-Tropsch diesel, dimethyl ether, naphtha, and electricity.

The ASPEN PLUS® Model and Dry Grind Production of Ethanol from Corn

The ASPEN model estimates the thermal and electrical energy used in each phase of ethanol and ethanol co-products production such as steeping, milling, liquefaction, saccarification, fermentation, distillation, drying the co-products, etc. These inputs were originally compiled in the 2001 "Net Energy Balance of Corn-Ethanol" study.

Computer programs which model the process and costs of ethanol production are available from the USDA'S Agricultural Research Service (ARS).

A series of computer models of the ethanol process and production economics have been developed by ARS engineers conducting research to reduce ethanol costs. These models are based on data from ethanol producers, engineering firms, equipment manufacturers and commercially available computer software for chemical process design and costing.

The information contained in these models includes the following:

- Volume, composition and physical characteristics of material flowing through the process
- Description, sizes and costs of process equipment
- Consumption and cost of raw materials and utilities
- Detailed estimates of capital and operating costs
- Quantity and cost of products and co-products

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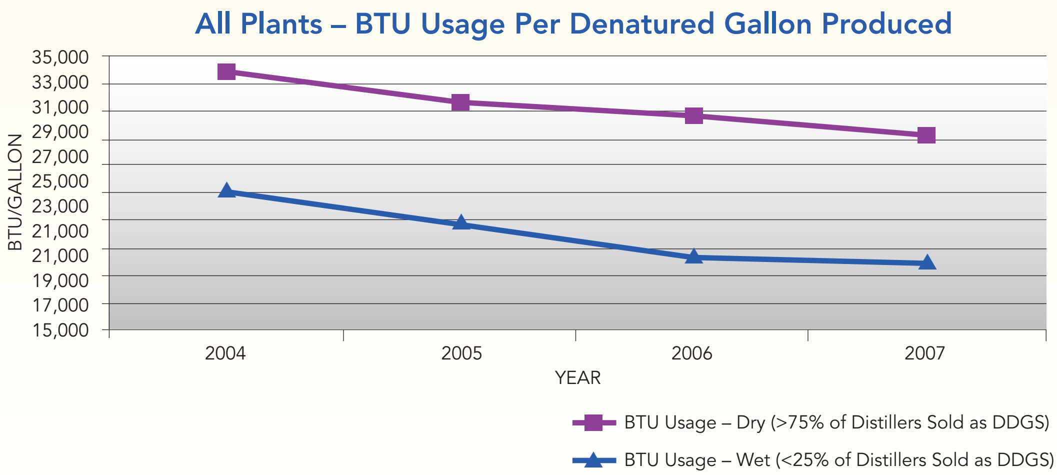
Improvements in Energy Efficiency at Ethanol Plants

One of the great success stories of the ethanol industry is the fact that many projects are community-based and funded. Often, equity in these plants is raised through thousands of individual shareholders who invest through public or private offerings. Christianson & Associates is the premier accounting firm in the United States that works with ethanol plants in terms of meeting all Securities and Exchange Commission and other legal requirements for investor owned facilities. As such, they are constantly monitoring the actual cost and performance of these plants in order to ensure that the projected returns associated with the equity offerings are based on accurate inputs and costs.

Christianson & Associates provides a comprehensive biofuels financial benchmarking subscription service. This benchmarking service measures over 80 financial and operational factors on a quarterly basis allowing ethanol plants to identify opportunities for improving processes and efficiencies. The benchmarking service allows ethanol plants to compare their data to the industry average and the top 25% are referred to as leaders.

An indisputable trend in the ethanol industry is that energy consumed per gallon of ethanol produced has improved significantly in the past 4 years. In a report issued by Christianson & Associates, the energy used to produce a gallon of denatured ethanol, measured as average BTUs consumed per gallon, was 31,588 in 2004. In 2007 that average had been reduced to 27,298 BTUs per gallon. This trend reflects both increased production from newer more efficient ethanol plants and the increased emphasis placed on energy efficiency and process improvements in existing facilities. The efficiency gains will not end there. Data from Christianson & Associates shows that industry leaders, the top 25% most energy efficient plants, have been able to reduce BTUs per gallon of ethanol produced to 20,545, which represents a 19% reduction in the BTUs consumed per gallon during the four-year period of 2004 through 2007. These efficiencies can be expected to be trickle down to existing plants and to be incorporated into new construction.

Another trend in the ethanol industry is the sale of wet distillers grains. A large portion of the energy consumed in an ethanol plant is in drying co-product distillers grains, with plants producing dried distillers grains consuming more energy than plants with wet production. The Christianson & Associates report shows four year



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efficiency improvements realized by plants selling wet distillers grains of over 21%. Once again even the best plants have shown significant reductions of nearly 23%, reducing BTUs per gallon of denatured production to 17,526.

Energy consumption is not the only thing going down:

Water use in ethanol production has also decreased. According to the U.S. Department of Energy's Biomass Program, 87% of corn grown for ethanol is not irrigated, and future production of ethanol from cellulose will reduce water use even more. In a report issued by the Institute for Agriculture and Trade Policy, process water use in plants has declined from approximately 5.8 gallons of water per gallon of ethanol in 1998 to about 4.2 gallons of water per gallon of ethanol in 2005. Current estimates are that ethanol plants use between 3 to 4 gallons of water for every gallon of ethanol produced. Technology improvements in plants have also allowed plants to use recycled water from waste water treatment plants and livestock facilities.

Farmers have contributed, too. Corn production per pound of fertilizer has gone up steadily. While fertilizer use in pounds per acre has remained fairly steady over the past 25 years, yields have nearly doubled from approximately 75 bushels per acre to about 150 bushels per acre.

"Introduction of the GREET and ASPEN PLUS® Models"
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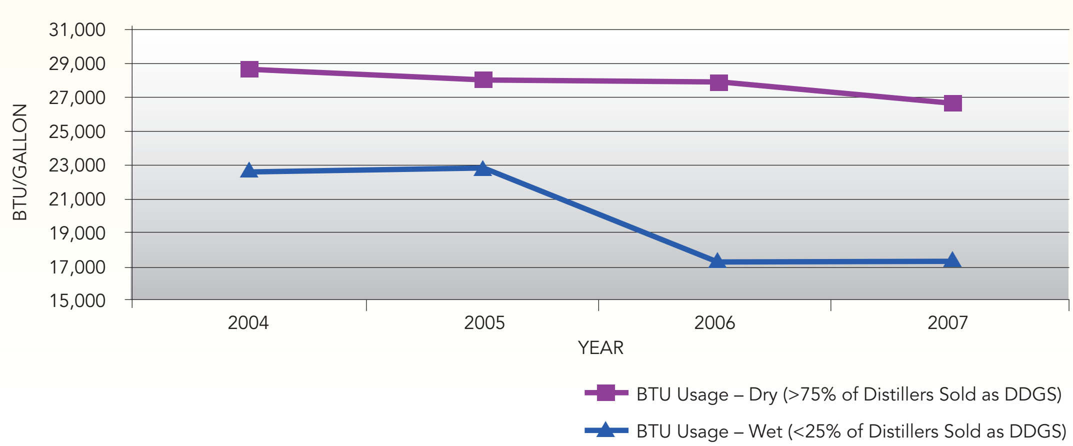
The models have applications in the following areas:

- Determination of the potential economic impact of ongoing and future ethanol research projects
- Evaluation of the impact that variations in the composition of corn would have on ethanol profitability
- Comparison of the economics of different existing and proposed ethanol production technologies
- Creation of new models by substituting different alternatives for various parts of the model
- Determination of the impact that changes in raw material, consumptions, or cost will have on ethanol production costs

The process model for the production of ethanol from corn by traditional dry milling facilities was written for and runs on ASPEN PLUS©, a process simulation program and is available upon request.

The cost model of this process runs on an Excel spreadsheet and is linked to the ASPEN PLUS© model.

Leaders – BTU Usage Per Denatured Gallon Produced



Energy Is Not the Only Product From An Ethanol Plant

A frequently overlooked area in the ethanol energy balance is that of ethanol co-products. Dry mill ethanol plants produce co-products, such as distillers grains for livestock feed and carbon dioxide used in the food and beverage industry as well as industrial uses.

New wet mill ethanol plants are producing many different products such as corn sweeteners in the summer months when demand is the highest, and then producing ethanol during the winter months. They also produce carbon dioxide, and corn gluten which is also used in the feeding of livestock. Ethanol plants are producing products that are in demand worldwide. This means that the energy used in the production of these products must be factored in as energy credits when quantifying the ethanol energy balance. It is common sense: if everything coming out of the process is not ethanol, then all the energy going in cannot be attributed to ethanol production.

It's a fact that ethanol has a positive energy balance and reduces America's reliance on foreign countries for oil. And, buying our energy here at home keeps our dollars at home and stems the flow of a staggering transfer of U.S. wealth to foreign countries. Every dollar we spend on the ethanol program – including dollars on energy – generates seven more dollars in our economy. When looking at all of the facts, counting BTUs truly misses the point.

Energy Use and Net Energy Value per Gallon *With* Co-product Energy Credits

Production Process	Milling Process		Weighted
	Dry	Wet	Average
Corn production	12,457	12,244	12,350
Corn transport	1,411	1,387	1,399
Ethanol conversion	27,799	33,503	30,586
Ethanol distribution	1,467	1,467	1,467
Total energy used	43,134	48,601	45,802
New energy value	33,196	27,729	30,528
Energy ratio	1.77	1.57	1.67

Energy Use and Net Energy Value per Gallon *Without* Co-product Energy Credits

Production Process	Milling Process		Weighted
	Dry	Wet	Average
Corn production	18,875	18,551	18,713
Corn transport	2,138	2,101	2,120
Ethanol conversion	47,116	52,349	49,733
Ethanol distribution	1,487	1,487	1,487
Total energy used	69,616	74,488	72,052
New energy value	6,714	1,842	4,278
Energy ratio	1.10	1.02	1.06

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CFDC CLEAN FUELS DEVELOPMENT COALITION

www.cleanfuelsdc.org

american coalition for ethanol

www.ethanol.org

Nebraska Ethanol Board

www.ne-ethanol.org

Maryland Grain Producers Utilization Board

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"The Net Energy Balance of Ethanol Production"* Issue Brief** was produced and is distributed as part of the ***Ethanol Across America education campaign.

The project was sponsored by the American Coalition for Ethanol, the Clean Fuels Development Coalition, the Maryland Grain Producers Utilization Board, Nebraska Public Power District and the Nebraska Ethanol Board.

Special thanks are extended to Dr. Roger Conway and Dr. Hosein Shapouri of the U.S. Department of Agriculture and the Office of Energy Policy and New Uses and the Office of Rural Development. Additional assistance was provided by Michael Wang of Argonne National Laboratory, John Christianson of Christianson & Associates, and Rick Handley of Handley & Associates.

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Produced in cooperation with the USDA UNITED STATES DEPARTMENT OF AGRICULTURE

ETHANOL ACROSS AMERICA

Ethanol Across America is a non-profit, non-partisan education campaign of the Clean Fuels Foundation and is sponsored by industry, government, and private interests. U.S. Senators Ben Nelson (D-NE) and Richard Lugar (R-IN) , Co-Chairmen. For more information, log on to **www.ethanolacrossamerica.net.**

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