Issue Brief:

Net Energy Balance of Ethanol Production

Fall 2004 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, sink, or otherwise move something. There are a million different types from a million different sources, whether it is gasoline to power an automobile, the gentle breeze that moves a leaf, or the carbs in a breakfast bar to get you going in the morning.

In the energy industry we have 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 bet to run a boiler than a ton of wood. In a perfect world that would be easy. If it took two tons of wood to run your boiler for an hour and only one ton of coal, you would go with the coal. Or would you?

Maybe you would ask questions like: Where does it come from? What does it take to make it? What does it cost? What form is it in? What other values or debits need to be looked at? These very questions are the basis for Argonne National Laboratory's GREET model. *(See story on page 3)*

In the ethanol industry, the comparison has always been seemingly 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." Or, they looked at the energy used to make the ethanol, and also deemed it inferior.

The reality is that it is far from straightforward, and comparisons based on raw numbers from an era of cheap energy are indeed comparing apples to oranges. *(By the way, was it really that cheap? See "The Real Cost of Oil" on page 6.)*

Inside

There are too many economic, social, and practical factors that need to be considered for anyone to simply put a pencil to the back of an envelope in an effort to determine that one form of energy is better than another. It needs to be looked at with respect to what it is replacing, and what that is achieving. Energy is also irrelevant unless you can turn it into the form in which you need it.

Yet, in the world of ethanol, the criticism of the program has been just that: It takes more BTUs to make it than it provides.

The ability of domestic, renewable ethanol to displace imported petroleum has historically been recognized as a primary benefit underlying support for ethanol production and use in the United States. However, detractors of ethanol have for thirty years argued 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. Usually it has been those getting displaced who would revert back to the BTU count.

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 inaccurate energy balance studies by intentionally using outdated information related to energy inputs associated with processing ethanol produced from grain. The reality is that the industry has policed itself, and steadily increased its output while decreasing the energy used.

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.

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.

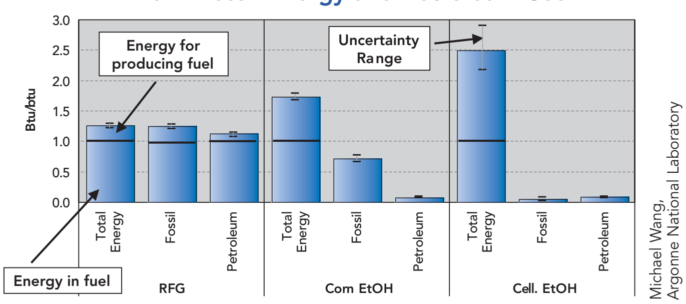
For example, it is unfair to attribute all the energy used to grow a bushel of corn and process it into its value as an energy product (i.e. ethanol). Ethanol production is a *co-product* of corn processing and therefore should only be charged with the energy that was used to turn it into ethanol. In 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 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 recognize that energy is going to be expended either 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 the energy used to make the steel that made the truck doing the hauling? Some detractors would have you believe so.

Reducing the energy balance argument to a battle of BTUs also ignores the practical fact that we need transportation fuels. While the majority of U.S. energy use is in the stationary sector to power our homes and businesses, we still use more than a third for transportation—an amount that is growing every day.

Let's say a pile of coal has a latent heat value of 1 million BTUs, but can be converted to liquid fuel that may represent a half million BTUs. Unlike the coal, the converted fuel can be put in your fuel tank. Which one is more valuable to you? Preserving BTUs, while staying at home because you cannot get to work, hardly gets us anywhere.

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



Energy Use for Each BTU of Fuel Used

It is equally important to look at energy in terms of what it is replacing. Typically, converting gases or solids to liquid yields a higher value, more usable energy form.

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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 that 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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Ethanol's Net Energy Value: A Summary of Major Studies	
Authors and Date	**NEV (Btu)**
Shapouri, et. al (1995) - USDA	+20,436 (HHV)
Lorenz and Morris (1995) - Institute for Local Self-Reliance	+30,589 (HHV)
Agri. and Agri-Food, CAN (1999)	+29,826 (LHV)
Wang, et. al. (1999) – Argonne National Laboratory	+22,500 (LHV)
Pimentel (2001) - Cornell University	-33,562 (LHV)
Shapouri, et. al, Update (2002) – USDA	+21,105 (HHV)
Kim and Dale (2002) - Michigan State University	+23,866 to +35,463 (LHV)
Shapouri, et. al, (2004) – USDA	+30,258 (LHV)

Therefore, energy balance does not mean energy benefits. We are trying to reduce fossil energy use for many obvious reasons. Ethanol from corn and from cellulosic biomass uses substantially less fossil fuel than processing petroleum based fuels. The result is fuel that truly reduces greenhouse gases, reduces imported oil and refined gasoline, and provides a range of economic and social benefits. This is why the GREET model is important, and helps to provide a total picture. *(See page 3)*

Even if we do limit the debate to BTUs, the second law of thermodynamics shows that any energy conversion process is going to result in a negative energy balance. Electric power plants using coal are only 35 percent efficient with a negative energy balance as much as -1.86. Ethanol has a positive energy balance, and an extremely high petroleum/fossil energy displacement ratio.

Ethanol critics such as Cornell University's Dr. David Pimentel, who argue that ethanol production uses more energy than it yields, typically select data and use assumptions that are outdated. While virtually all analyses refute Pimentel's conclusions, a 2002 Michigan State University study notes several discrepancies in Pimentel's methodology and conclusions:

- 1992 corn yields and energy inputs were used. Today's yields have greatly increased and the use of pesticides and fertilizers has gone down.
- Figures for the energy used to manufacture ethanol data were from 1979.
- Irrigation energy costs are included for all corn used in ethanol manufacturing, though only 15% of U.S. corn is irrigated.
- Distillers dried grains are not used as an energy credit.

Dan Walters provides a similar perspective. According to Walters, a University of Nebraska-Lincoln soil scientist, these reports continue to rely on outdated data. "The problem is that it's all old data," says Walters. His claim is that the negative energy numbers are derived from the data collected in the late 1980's and early 1990s.

The means of calculating an energy balance have been greatly distorted, especially by those lobbying against ethanol incentive programs.

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 15% more ethanol from a bushel of corn, and using 20% less energy to do so than just five years ago.

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 less than or equal to 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.

Recent studies have shown that the ethanol energy balance is improving by the year. These studies are showing that the energy output to energy input ratio for converting irrigated corn to ethanol is now 1.67 to 1. In a July 1995 U.S. Department of Agriculture, Economic Research Service Report entitled "Estimating the Net Energy Balance of Corn Ethanol", it was concluded that the ethanol energy

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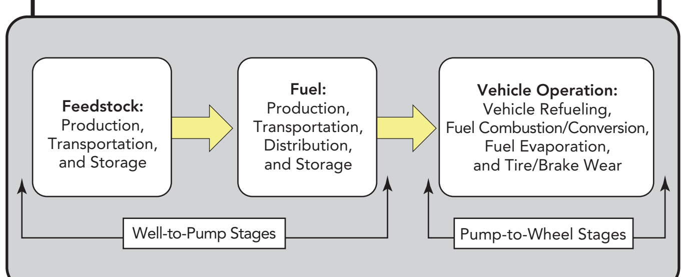
2. Fuel-cycle emissions of greenhouse gases
   a) Carbon dioxide (CO_2) (with a global warming potential [GWP] of 1),
   b) Methane (CH_4) (with a GWP of 23), and
   c) Nitrous oxide (N_2O) (with a GWP of 296);

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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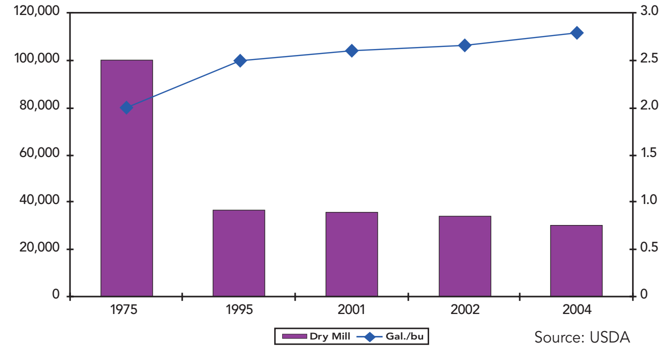
balance had a gain of 24%. That same report was revisited the next year, in a presentation entitled "Energy Balance of Corn Ethanol Revisited", the authors concluded the ratio had risen to 34%. This number is reinforced by a 2002 report, "The Energy Balance of Corn Ethanol: An Update," published by the USDA's Office of the Chief Economist and Office of Energy Policy and New Uses. The report concluded that ethanol production is energy efficient because it yields 34% more energy than is used. According to Agricultural Secretary Ann M. Veneman, "This new research shows that ethanol is a valuable resource." The USDA yet again, in June 2004, looked at this issue and determined that ethanol continues to be more efficient, and now provides the aforementioned 1.67 to 1 gain in energy.

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



Source: USDA

Many advances have led to the surge in ethanol production efficiency. One key issue is the ability to produce more gallons of ethanol per bushel of corn. In the early 1990's, plants were able to produce about 2.5 gallons of ethanol per bushel. That number has since increased to between 2.7 and 2.8 gallons per bushel today.

The Real Cost of Oil

Despite the low energy costs the U.S. enjoyed for decades, calculating the value of BTUs is nonetheless an economic exercise. So part of the BTU counting craze included cost counting.

Because of the low cost of oil to consumers, any alternative fuel, new-kid-on-the-block trying to break into the business was faced with a tough challenge: "Can you be cheaper than oil?" The irony is that it would be hard to be more expensive than oil, if all the external factors in the cost of oil were considered. Remember, price is not cost, and that is an important distinction.

What we have paid at the pump is only a small portion of the real cost of oil. It does not reflect the environmental, military, economic, and other costs directly related to our dependence on imported oil. It is critical to understand this reality, and help put in perspective the value of domestic replacement fuels, regardless of cost or BTU rhetoric.

The following excerpt is from the Report of the National Defense Council Foundation in November 2003 entitled *"America's Achilles Heel: The Hidden Costs of Imported Oil."* The tables on pages 8 and 9 outline the cost estimates for defending Middle East oil flows that each of the analytical frameworks provide as well as a per barrel and per gallon cost figure.

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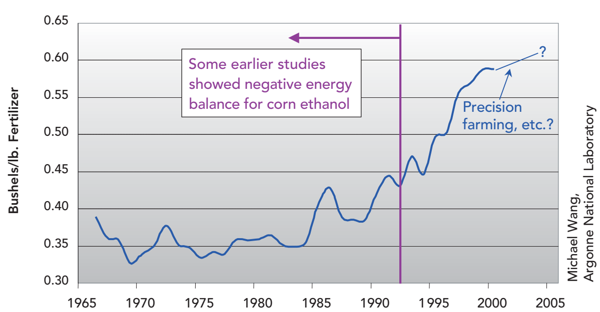
Another element to ethanol's increased efficiency is the advances in production agriculture. The largest energy factor in raising corn is nitrogen, accounting for roughly 40 percent of all energy needed. According to Walters, nitrogen efficiency has improved immensely, and continues to improve at a rate of .013 bushels of grain per pound of nitrogen. The Argonne and USDA studies also make this point. In fact, the improvements since 1995 have been astounding, making any studies using data prior to that time completely obsolete.

U.S. Corn Output Per Pound of Fertilizer Used Has Risen (3-yr Moving Average)



Another key factor in farming efficiency is that of yield. Yield plays a major role in determining net energy value in the energy balance. In fact, a one percent increase in corn yield will raise NEV 0.37 percent. Thanks to better corn varieties, improved farming practices, and farming conservation measures, U.S. corn yield per acre has increased during the last 30 years by over 50%, to about 125 bushel per harvested acre.

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"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 coproducts

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"The Real Cost of Oil" continued from page 6

THE COST OF DEFENDING PERSIAN GULF OIL

Military spending to protect the Persian Gulf's oil fields can be divided into two broad categories:

Ongoing Expenditures: Outlays for permanent military capabilities that are maintained to assure the ability to defend Middle East oil supplies.

Onetime Expenditures: Outlays that are made for specific items such as pre-positioned supplies and the ships to carry them. It also includes the cost of specific military operations such as Operation Desert Shield/Storm. For purposes of analysis, onetime expenditures are amortized over a ten-year period.

The bulk of ongoing military expenditures are found within the budget of the United States Central Command, or "CENTCOM."

CENTCOM's area of responsibility or "AOR" stretches from the Central Asian States to the Horn of Africa and comprises an area of approximately 6.5 million square miles holding 25 countries and 522 million people. According to its official description, CENTCOM's operations focus "primarily on the Middle East." Indeed, five of its seven most recent deployments have been to the Persian Gulf.

Since CENTCOM's operations are not limited to the Middle East, it is necessary to determine what portion of its expenditures can properly be attributed to defending oil. A detailed analysis of its "Order of Battle" (e.g. a list of all of its units and their missions), suggests that at least half of its personnel and operating and maintenance budgets can be properly allocated to the defense of Middle East oil. In addition to these basic outlays within CENTCOM's budget, expenditures for pre-positioned equipment, strategic mobility and Southwest Asia contingencies from the broader Department of Defense budget may also be assigned to this purpose.

	1993-2003 (Billions)		
ONGOING COSTS	**Budget-Based**	**State Formula**	**Minimalist**
Personnel, O&M	$42.790	$35.700	$5.418
Prepos. & Strategic Mob.	$ .518	$ .518	$.518
S.W. Asia Contingencies	$1.100	$1.100	$1.100
Total Ongoing	$44.408	$37.318	$7.099
One-Time Amortized	$.989	$.989	N/A
Total Defense Costs	$49.088	$38.307	
	Persian Gulf Only		
Per Barrel cost	$45.54	$38.43	$7.12
Per Gallon cost	$1.08	$.91	$.17
	All Imports		
Per Barrel Cost	$10.71	$ 9.03	N/A
Per Gallon Cost	$.25	$.22	
	2003-2013 (Billions)		
Total Defense Costs	$49.088	$41.988	$7.099
	Persian Gulf Only		
Per Barrel Cost	$49.24	$42.12	$7.12
Per Gallon Cost	$1.17	$1.00	$.17
	All Imports		
Per Barrel Cost	$11.58	$9.90	N/A
Per Gallon Cost	$.28	$.24	N/A

Military expenditures related to imports.

An alternative method of analyzing military expenditures is to employ a formula designed by the United States Department of State. The State Department method is based on an arbitrary "cost per soldier."

A third approach is to look only at the cost of personnel and equipment specifically stationed in the Persian Gulf. This may be called the "minimalist" approach. There is also some debate over whether to amortize the costs over the total volume of oil imports, or just those flowing from the Persian Gulf. Because substantial expenditures to expand pre-positioned equipment and materiel are anticipated after 2003, it is necessary to look at the cost figures within two separate time frames: 1993 to 2003 and 2003 to 2013. It is also instructive to see how the aggregate expenditures translate into a cost per barrel of oil or cost per gallon of refined petroleum product.

THE HIGH COST OF IMPORTS		
JOBS IMPACT		828,400
SUBTOTAL: CURRENT COST		***$36.7 Billion***
DIRECT INVESTMENT LOSS		$35.2 Billion
INDIRECT INVESTMENT LOSS		$88.0 Billion
SUBTOTAL: INVESTMENT LOSS		***$123.2 Billion***
TOTAL ANNUAL COST:		$159.9 Billion
STATE AND FEDERAL REVENUE LOSSES		$13.4 Billion
TOTAL ECONOMIC LOSSES	***$173.3 Billion***	***$173.3 Billion***
OIL SHOCKS	$74.8 Billion	$82.5 Billion
GRAND TOTAL	***$248.1 Billion***	***$255.8 Billion***

Total economic impact of imports.

"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.

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. These co-products, such as distillers feeds for livestock, increase efficiency by eliminating the need to produce such products had they not been made during ethanol production.

New wet mill ethanol plants are producing many different products. These plants are usually producing large amounts of corn sweeteners in the summer months when demand is the highest, and then producing ethanol during the winter months. They are also producing carbon dioxide which is used in soft drinks, and corn gluten which is used in the feeding of livestock. These 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 energy, then all the energy going in cannot be counted.

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The most recent USDA study addresses this issue head on by using the ASPEN PLUS® model to allocate energy between ethanol and byproducts from an ethanol plant. With this model, approximately 65% of the total energy used in an ethanol plant is related to the ethanol, with 35% related to by-products. It is a simple and straightforward means of finally looking at this issue. With that adjustment, and the increased efficiencies, the picture improves as evidenced by the new USDA findings.

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

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 feedgrains. 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 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

In addition to the fact that ethanol has a positive energy balance, another key fact must always be considered: ethanol lessens 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.

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Maryland Grain Producers
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www.burnsmdc.com

American Coalition for
ETHANOL
www.ethanol.org

CFDC CLEAN FUELS DEVELOPMENT COALITION
www.cleanfuelsdc.org

Nebraska Ethanol Board
www.ne-ethanol.org

Nebraska Public Power District
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