THE 2001 NET ENERGY BALANCE OF CORN-ETHANOL

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ABSTRACT

This report estimates the net energy balance of corn ethanol utilizing the latest survey of U.S. corn producers and the 2001 U.S. survey of ethanol plants. The major objectives of this report are to improve the quality of data and methodology used in the estimation. This paper also uses ASPEN Plus, a process simulation program, to allocate total energy used to produce ethanol and byproducts. The results indicate that corn ethanol has a positive energy balance, even before subtracting the energy allocated to by products. The net energy balance of corn ethanol adjusted for byproduct credits is 27,729 and 33,196 Btu per gallon for wet- and dry-milling, respectively, and 30,528 Btu per gallon for the industry. The study results suggest that corn ethanol is energy efficient, as indicated by an energy output/input ratio of 1.67.

Keywords: Corn-ethanol, energy inputs, dry-and wet-milling, net energy balance

INTRODUCTION

USDA's net energy balance of corn-ethanol was published in 1995, 2002, and 2003 in the American Society of Agricultural Engineers (ASAE), Shapouri et al. Since 1970, many authors have studied the net energy balance of corn-ethanol. The major objective of this report is to improve the general estimation procedure. These improvements include: (1) regular updating of the estimates based on the latest data on corn production and corn yield, (2) improving the quality of estimates for energy used in manufacturing and marketing nitrogen fertilizer, (3) improving the quality of estimates for energy used to produce seed-corn, and (4) enhancing the methodologies used in allocating the energy used in ethanol production (to byproducts and ethanol). In contrast to three previous studies, all energy inputs are reported in low-heat value (LHV).

During the past 2 years, David Pimentel, 2003, Tad Patzek, 2003, and Andrew Ferguson, 2003, criticized USDA's studies of the net energy balance of corn ethanol. It is argued that USDA underestimates energy used in the production of nitrogen fertilizer and the energy used to produce seed-corn, over estimating the energy allocated to produce corn-ethanol byproducts. They also argued that USDA excludes energy used in corn irrigation and secondary energy inputs used in the production of corn, such as farm machinery and equipment and cement, steel, and stainless steel, used in the construction of ethanol plants.

THE NET ENERGY BALANCE

This paper, unlike the Dr. Pimentel report, 2003, is based on straightforward methodology and highly regarded quality data from the 2001 Agricultural Resource Management Survey (ARMS), Economic Research Service, ERS/USDA, 2001 Agricultural Chemical Usage, and 2001 Crop Production, National Agricultural Statistics Service, NASS/USDA, and the 2001 survey of ethanol plants.

Direct energy used on farms, such as gasoline, diesel, LP gas (LPG), natural gas, and electricity, for the production of corn, including irrigation by States from 2001 ARMS, are available on the ERS Web site. The number of seed-corn planted per acre in 2001, custom work expenditure, tons of lime used per acre, and purchased water were also from the 2001 ARMS. Quantities of fertilizers and pesticides used per acre of corn in 2001 were published by NASS. Although corn is produced in every State, we focused our analysis on the major corn-producing States: Illinois, Indiana, Iowa, Minnesota, Nebraska, Ohio, Michigan, South Dakota, and Wisconsin. In 2001, these nine States accounted for 79 and 92 percent of U.S. corn and ethanol production, respectively.

Corn yield is a critical part of the net energy balance estimation. Although the corn yield has been rising over time, the annual variation is very volatile. Therefore, we used a 3-year average yield instead of the average yield for the survey year. The 2000-02 weighted average corn yield in each State was used to convert farm inputs from a per acre basis to a per bushel basis (2001 Crop Production, NASS). Table 1 shows the nine-State energy input data per acre of corn and nine-State weighted average for the 2001 ARMS.

Table 1--Energy-related inputs used to grow corn in nine States and nine-State weighted average, 2001

		IL	IN	IA	MN	NE	OH	MI	SD	WI	9-State Weighted average
Yield 2000-02 average	Bushels/acre	146.31	141.85	152.06	144.35	133.66	125.8	114.78	105.82	131.48	139.34
Seed	Kernels/acre	29158	28281	29855	30816	26619	28934	27867	25270	29860	28739
Fertilizer:											
Nitrogen	pounds/acre	154.53	147.33	125.04	113.74	131.73	168.3	125.52	109.09	106.6	133.52
Potash	pounds/acre	116.81	132.32	68.72	61.82	21.14	112	102.1	31.99	56.01	88.2
Phosphate	pounds/acre	80.88	67.28	57.32	46.31	35.18	67.39	50.06	45.54	37.43	56.81
Lime	pounds/acre	20	20	20	0	0	20	20	0	60	15.67
Energy:											
Diesel	Gallons/acre	3.7	4.6	4.6	5.4	12.4	4.3	7.2	4.4	7.4	6.85
Gasoline	Gallons/acre	1.5	2.1	1.2	1.7	2.1	1.6	2.5	1.5	1.4	3.4
LPG	Gallons/acre	2.8	3.2	7.2	8.5	4.1	5.6	3.6	0.5	1.9	3.42
Electricity	kWh/acre	9.6	28.3	16.8	26.8	152.5	10	25.5	27.4	6.6	33.59
Natural Gas	Cubic ft/acre	76.9	144.2	0	45.8	964	164	223.1	7	124	245.97
Custom work	Dol./acre	13.45	7.8	9.9	8.58	7.93	8.29	9.8	9.3	15.26	10.12
Chemicals	Pounds/acre	3.28	3.19	2.84	2	2.17	3.7	3.15	1.83	2.17	2.66
Purchased water	Dol./acre	0	0	0	0	1.2	0	0	0	0	0.18

Source: USDA, Economic Research Service and Office of Energy Policy and New Uses.

In previous studies, we assumed that energy used to produce seed-corn is equal to 1.5 times the energy used to produce corn. The review of literature and comments on our reports indicated that seed-corn production requires more energy because the seed-corn yield per acre is low and requires a considerable amount of electrical energy to process seed-corn including drying, shelling, grading, cleaning and storage. Based on an unpublished report prepared by Michael Graboski, 2002, for the National Corn Grower Association, the energy required for growing and processing seed-corn is estimated at 4.7 times that required for production of corn. The factor of 4.7 is used in this study.

The amount of energy used to produce a pound of nitrogen has been estimated in several studies. The values range from 18,392 Btu of high heat value (HHV) per pound, Shapouri et al, 2002, to over 33,590 Btu LHV per pound, Pimentel 2003. For this report, we asked Keith Stokes, President of the Stokes Engineering Company and fertilizer expert, to estimate the energy used in the production of nitrogen, phosphate, and potash fertilizers. His estimates of energy used (LHV) to make and deliver nutrients are 24,500 Btu per pound of N, 4,000 Btu per pound of P_2O_5, and 3,000 Btu per pound of K_20.

The energy used to produce herbicides and insecticides are from Wang et al.1999, the Greenhouse Gas Regulated Emissions and Energy Use in Transportation (GREET) model, Argonne National laboratory. More than 153,000 Btu of energy is required to produce a pound of herbicides, and about 158,000 Btu of energy is required to produce a pound of insecticides. A weighted average of over 154,000 Btu of energy is used per pound of pesticides. Farm-related energy inputs are converted per bushel and then to Btu of energy per bushel of corn by multiplying each input by its LHV. The energy required for hauling these inputs to farms, excluding fertilizer, was also estimated. The energy used to produce fertilizers includes energy used to deliver fertilizer to farm. The total energy requirements for farm inputs are given in Table 2.

The energy associated with transporting the corn from local storage facilities to ethanol plants was estimated by the GREET model. The average energy used for transporting a bushel of corn was 5,636 Btu or about 2,120 Btu per gallon of ethanol.

Ethanol production facilities include both dry- and wet-milling operations. Dry mills are usually smaller than wet mills and are built primarily to produce ethanol. Wet mills are bio-refineries and produce a wide range of products such as ethanol, high fructose corn syrup (HFCS), starch, food and feed additives, and vitamins. Thermal and electrical powers are the main types of energy used in both types of processing plants. Wet mills usually generate both electrical and thermal energy from burning natural gas or coal. Dry mills use natural gas to produce steam and purchase electricity from a utility.

The energy used to convert corn to ethanol is based on a U.S. survey conducted in 2001 by BBI International. On the average, dry mill ethanol plants used 1.09 Kwh of electricity and about 34,700 Btu of thermal energy (LHV) per gallon of ethanol. When energy losses to produce electricity and natural gas were taken into account, the average dry mill ethanol plant consumed about 47,116 Btu of primary energy per gallon of ethanol produced. Wet mill ethanol plants that participated in the survey used 49,208

Table 2--Total energy requirements of farm inputs for nine State and nine-State weighted average, 2001

	IL	IN	IA	MN	NE	OH	MI	SD	WI	9-State Weighted average
					BTU/bushel					
Seed	525	557	451	512	804	780	827	623	548	603
Fertilizer:										
Nitrogen	25876	25446	20147	19305	24146	32764	26792	25257	19864	23477
Potash	2395	2798	1356	1285	474	2670	2669	907	1278	1899
Phosphate	2211	1897	1508	1283	1053	2142	1745	1721	1139	1631
Lime	76	79	73	0	0	89	97	0	255	63
Energy:										
Diesel	3853	4941	4609	5700	14136	5207	9558	6336	8576	7491
Gasoline	1478	2135	1138	1698	2266	1834	3141	2044	1536	3519
LPG	1644	1938	4067	5058	2635	3823	2694	406	1241	2108
Electricity	614	1868	1035	1739	10685	744	2081	2425	470	2258
Natural Gas	550	1063	0	332	7544	1363	2033	69	986	1846
Custom work	2001	1197	1417	1294	1291	1434	1859	1913	2526	1581
Chemicals	3453	3464	2877	2134	2501	4530	4227	2664	2542	2941
Purchased water	0	0	0	0	946	0	0	0	0	136
Input hauling	143	167	178	176	242	209	254	121	251	202
Total	44821	47551	38856	40516	68723	57590	57977	44486	41212	49753

Btu per gallon of natural gas and coal, on average, to produce steam and electricity in the plants. After adjustments for energy losses to produce natural gas and coal, on the average, a wet mill ethanol plant used 52,349 Btu of energy to make a gallon of ethanol.

The average energy associated with the transport of ethanol from ethanol plants to refueling stations was estimated by the GREET model. The average energy used for transporting a gallon of ethanol was 1,487 Btu per gallon for both dry and wet milling.

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, including hauling corn from farms or grain elevators to ethanol plants, should be allocated to ethanol and byproducts.

In the previous studies, we used a replacement method to allocate total energy to ethanol and byproducts. For this report, we used ASPEN Plus, a process simulation program, to allocate the energy used in the plants to ethanol and byproducts. On the average, 59 and 64 percent of the energy used to convert corn to ethanol is allocated to ethanol in dry- and wet-mills respectively.

Energy is used to produce and transport corn to ethanol plants allocated to starch and other corn kernel components, such as fiber, germ, and protein. Only starch is converted to ethanol. On the average, starch accounts for 66 percent of the corn kernel weight (15 percent moisture). Therefore, 66 percent of energy used to produce and transport corn to ethanol plants is allocated to ethanol and 34 percent to byproducts.

Energy used in the production of secondary inputs, such as farm machinery and equipment used in corn production, and cement, steel, and stainless steel used in the construction of ethanol plants, are not included in our study. Available information in this area is old and outdated. Pimentel, in his latest report (2003), used the 1979 Slesser and Lewis to estimate the energy used in the production of steel, stainless steel, and cement.

RESULTS

All energy inputs used in the production of ethanol is adjusted for energy efficiencies developed by GREET model. The estimated energy efficiencies are for gasoline (80.5 percent), diesel fuel (84.3 percent), LPG (98.9 percent), natural gas (94 percent), coal (98 percent), electricity (39.6 percent), and transmission loss (1.087 percent). After adjusting the energy inputs by these energy efficiencies, the total estimated energy required to produce a bushel of corn in 2001 was 49,753 Btu.

Table 3 summarizes the input energy requirements, by phase of ethanol production on a Btu per gallon basis (LHV) for 2001, without byproduct credits. Energy estimates are provided for both dry- and wet-milling as well as industry average. In each case, corn ethanol has a positive energy balance, even before subtracting the energy allocated to byproducts.

Table 4 presents the final net energy balance of corn ethanol adjusted for byproducts. The net energy balance estimate for corn ethanol produced from wet-milling is 27,729 Btu per gallon, the net energy balance estimate for dry-milling is 33,196 Btu per gallon, and the weighted average is 30,528 Btu per gallon. The energy ratio is 1.57 and 1.77 for wet- and dry-milling, respectively, and the weighted average energy ratio is 1.67.

Table 3--Energy use and net energy value per gallon without coproduct energy credits, 2001

	Milling process		Weighted
Production process	Dry	Wet	average
	Btu per gallon		
Corn production	18875	18551	18713
Corn transport	2138	2101	2120
Ethanol conversion	47116	52349	49733
ethanol distribution	1487	1487	1487
Total energy used	69616	74488	72052
Net energy value	6714	1842	4278
Energy ratio	1.10	1.02	1.06

Table 4--Energy use and net energy value per gallon with coproduct energy credits, 2001

	Milling process		Weigted
Production process	Dry	Wet	average
	Btu per gallon		
Corn production	12457	12244	12350
Corn transport	1411	1387	1399
Ethanol conversion	27799	33503	30586
ethanol distribution	1467	1467	1467
Total energy used	43134	48601	45802
Net energy value	33196	27729	30528
Energy ratio	1.77	1.57	1.67

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