United States Department of Agriculture

Office of the Chief Economist

Office of Energy Policy and New Uses

Agricultural Economic Report Number 841

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Hosein Shapouri
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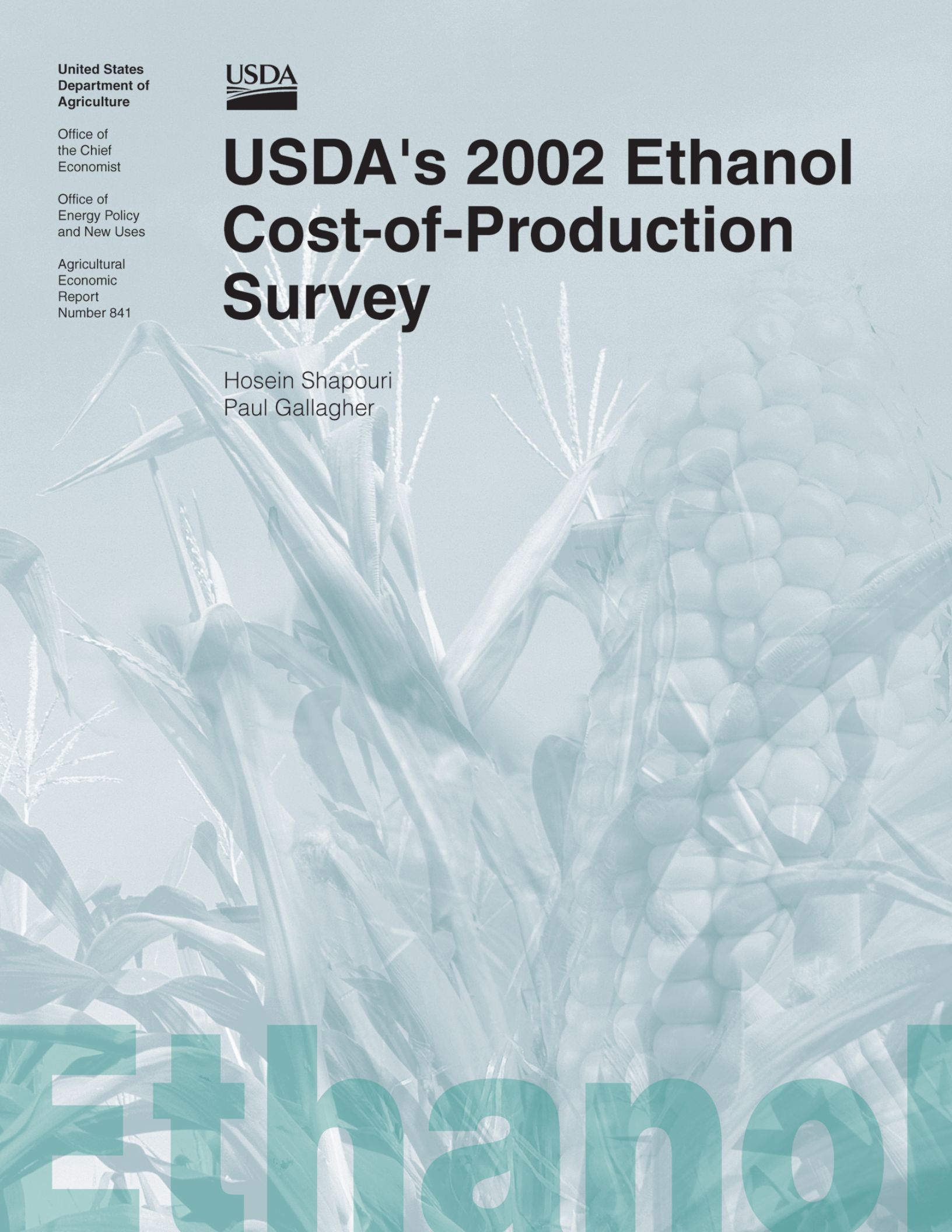

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July 2005

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Abstract

In 2003, the U.S. Department of Agriculture surveyed 21 dry-mill ethanol plants to estimate their 2002 production costs, including both variable (feedstock and plant operation) and capital expenses. These plants produced about 550 million gallons of ethanol in 2002. Net feedstock costs for the surveyed plants ranged from 39 to 68 cents per gallon in 2002. For cash operating expenses, the average energy expenditure was 17.29 cents per gallon. Labor costs ranged from 3 to 11 cents per gallon, maintenance costs from 1 to 7 cents, and administrative costs from 1 to 18 cents. For capital expenditures, new plant construction costs from $1.05 to $3.00 per gallon of ethanol. Average investment to expand existing ethanol production capacity was 50 cents per gallon; hence, expansion tends to cost less than new capacity. Comparison with a 1998 survey of ethanol producers showed that total operating costs in 2002 had changed very little from 1998. It also showed that the average cost of building new plants had dropped, possibly due to designs that emphasize economies of scale.

Keywords: Ethanol costs of production, net corn costs, operating costs, dry mills, wet mills.

About the Authors

Hosein Shapouri is an economist with the Office of Energy Policy and New Uses in USDA's Office of the Chief Economist. Paul Gallagher is a professor at Iowa State University, Ames.

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Summary

The ethanol industry's share of the U.S. fuel market is continuing to grow. Ethanol production capacity increased from 200 million gallons per year in 1980 to over 3,600 million gallons in 2004, and the number of ethanol plants increased from fewer than 20 to more than 80.

A shift in the use of ethanol, creating new markets, is partly responsible for its expanded production. In the early 1980s, ethanol was produced as a fuel to extend the supply of gasoline. Now it is used mainly as a gasoline additive for its oxygen and octane content. In 2004, more than 80 percent of the ethanol produced was used in State oxygen-mandated markets and in a winter-oxygenated program. The rest was used to enhance the octane rating in gasoline throughout the United States. Ethanol production has also been boosted by improved technologies for growing corn, a major input; corn yields increased an average of 40 percent per acre from 1979-81 to 2002-04.

The data are mainly from a questionnaire to ethanol processors about their costs for 2002. The survey was designed by USDA's Office of Energy Policy and New Uses and Bryan and Bryan Inc. International. The questionnaire is similar to a survey of 1998 production costs (for wet-and dry-mill ethanol plants). This report summarizes results from 21 dry-mill ethanol plants. (Wet mills did not participate in the 2002 survey.) Generally, the production cost data reported here refer to calendar year 2002. Where more recent data were available, they have been included, with the year specified.

Operating Costs—Ethanol production has two cost components, capital costs and variable costs, the latter including net feedstock costs and cash operating expenses. The report provides detailed information for each of these components.

Feedstock costs include expenses for purchasing corn, sorghum, and other feedstock. The survey showed that large ethanol plants (with an annual production capacity of 40 million to 100 million gallons) purchased sorghum and other feedstocks as well as corn, whereas small plants (with a capacity of 40 million gallons or less) purchased only corn.

Variable operating expenses include electricity, fuels, waste management, water, enzymes, yeast, chemicals, denaturant, maintenance, labor, administrative costs, and other costs. Energy costs (electricity and fuels), the largest operating expenses, averaged 17.29 cents per gallon of ethanol produced in 2002. The cost per gallon was more than 5 cents cheaper for larger plants, which are more energy efficient than small plants. Labor costs ranged from 3 to 11 cents per gallon, and management, administration, insurance, and tax expenses from 1 to 18 cents per gallon. Some of these differences may be due to variations in accounting for management and personnel.

A comparison of the 1998 and 2002 surveys shows that total operating costs in 2002 changed very little from 1998. Total cash operating costs were 42 cents per gallon in 1998 vs. 41 cents in 2002. Fuel costs in 2002 were 50 percent higher than in 1998 due to higher prices for natural gas. However, fuel increases were offset by labor and enzyme costs that were 26 and 35 percent lower, respectively, in 2002 than in 1998.

Capital Costs—For new plants, construction costs ranged from $1.05 to $3.00 per gallon of ethanol. The average cost of building new plants is lower than in the past, possibly due to designs that exploit economies of scale. Of the 21 plants responding to the survey, 16 increased their capacity in 2002 by a combined 253 million gallons per year. Average investment to expand existing ethanol production capacity was 50 cents per gallon, ranging from 20 cents to $1.00. Hence, expansion tends to cost less than new capacity.

Introduction

Ethanol is a clean renewable gasoline additive produced from domestically grown feedstocks such as corn, sorghum, barley, and wheat. In 1980 to 2004, the ethanol industry and its role expanded significantly. Ethanol production capacity increased from 200 million gallons per year in 1980 to over 3,600 million gallons by late 2004. During the same period, the number of ethanol plants increased from fewer than 20 to more than 80. More than 1.35 billion bushels of corn were used in ethanol processing in 2004. Roughly equal amounts of corn were used for food, seed, and other industrial uses.

New markets partly explain the growth in ethanol production since 1980. In the early 1980s, ethanol was produced as a fuel, and the goal was to extend the supply of gasoline. Now, however, ethanol is produced and sold mainly as a gasoline additive for its oxygen and octane content. Ethanol contains 35 percent oxygen by weight with an octane rating of 113. The main ethanol programs include the winter oxygenated-gasoline program, reformulated-gasoline program, and mandated market-use programs—such as in Minnesota. Ethanol is also a perfect substitute for MTBE (methyl tertiary butyl ether), a gasoline additive made from methanol. More than 80 percent of the ethanol produced in 2004 was used in oxygen-mandated markets such as California, New York, Connecticut, Illinois (Chicago), Wisconsin (Milwaukee), and Minnesota, and in a winter-oxygenated program. The rest was used to boost the octane rating in gasoline across the country.

Improvements in corn production are also part of the reason for growth in ethanol production. Corn farmers have contributed steadily growing input supplies and improved input quality to the ethanol industry. The average corn yield per acre increased from 103 bushels per acre in 1979-81 to about 144 bushels per acre in 2002-04, a 40-percent increase for the period. The increase in production came primarily from improvements in productivity in corn farming due to adoption of new technologies. In fact, farm inputs used per bushel of corn (such as energy, fertilizers, chemicals, labor, and farm machinery and equipment) remained unchanged or declined slightly during the last decade. New technologies—such as genetically modified seeds, slow-release nitrogen fertilizer, precision farming, variable rate technology, yield mapping, and center-pivot irrigation systems—also improved crop yields and increased farm input efficiency. The result was a gain in corn productivity. Much of the credit goes to the high quality of research performed by the seed companies producing high-yield varieties; seeds with high tolerance for herbicides, diseases, and insects; and corn with higher fermentable starch levels.

Ethanol Industry

The technology and structure of the ethanol industry have changed, along with the expanding input and product markets from 1980 to 2004. In the early 1980s, there were a few large wet-mill ethanol plants and many small inefficient dry-mill ethanol plants. Most of the small ethanol plants went out of business during the 1980s because they were extremely inefficient. With an improvement in conversion technologies, larger and more efficient dry-mill ethanol plants were constructed. In 2004, about 40 dry-mill ethanol plants with an annual production capacity ranging from 40 million to 100 million gallons per year were in operation or under construction. There were also more than 40 smaller dry-mill ethanol plants, with an annual production capacity of less than 40 million gallons, in operation or under construction.

Several new processing techniques have reduced input requirements and improved process yields. First, energy-saving technologies, such as the re-use of liquefaction and scarification energy for removing water from ethanol in the distillation column, have led to a decline of more than 70 percent in the thermal and electrical energy used to produce a gallon of ethanol. New dry-mill ethanol plants now use only about 30,000 Btu of thermal energy and less than 1 kilowatt hour of electricity to produce 1 gallon of ethanol and byproducts. Second, process automation and distributed control systems have reduced labor requirements. Third, several improvements in fermentation technology, the most important of which is simultaneous scarification and fermentation, have improved yields. (Other fermentation improvements include thermo-tolerant yeast and yeast propagation improvements.) Plants are now able to produce more than 2.8 gallons of ethanol per bushel of corn compared with less than 2.5 gallons of ethanol per bushel of corn in 1980. These new technologies have substantially lowered ethanol production costs.

USDA's 2002 Survey

A questionnaire to collect information about ethanol processors for 2002 from dry- and wet-mill ethanol plants was designed by the Office of Energy Policy and New Uses, U.S. Department of Agriculture (USDA), and Bryan and Bryan Inc. International (BBI)—an ethanol consulting company in Cotopaxi, CO. The packages sent to ethanol producers contained a survey questionnaire, cover letter, confidentiality agreement forms, and a copy of the previous survey (Shapouri, Gallagher, and Graboski, 2002). BBI conducted ethanol production cost interviews during 2003.

The survey provided a complete picture of the dry-mill industry in 2002. Thirty-four dry-mill ethanol plants responded to the survey, accounting for 30 percent of national dry-mill capacity. However, 13 of the responses were incomplete and were not usable. So this report summarizes the results of the 21 dry-mill ethanol plants. These ethanol plants produced about 550 million gallons of ethanol in 2002. The wet mills did not participate in the survey.

The primary goal of this survey was to obtain costs of production. But we also surveyed and report results for other aspects of firm performance, such as processing yields input requirements and marketing practices for ethanol and byproducts.

Costs of Production

The total cost of producing ethanol is composed of two components, variable costs and capital costs. Detailed information for net feedstock costs and cash variable operating costs are provided in this report. We also report some information about the cost associated with building and expanding plant capacity. To maintain confidentiality, cost data were aggregated by the production capacity of ethanol to yield the industry's average costs for the dry-mill process by size.

Variable Costs

In turn, we again divided variable costs into two main components, feedstock costs (the costs of the corn after accounting for byproduct revenues) and cash operating expenses (costs of operating the processing plant). Further, variable costs are divided into two groups based on the plant production capacities—small and large. The variable cost data from the 2002 survey are provided in table 1.

Table 1
Undenatured ethanol cash operating expenses and net feedstock costs for dry-milling process by plant size, 2002

	Unit	All dry mills	Small	Large
Feedstock:				
Corn	1,000 bu	193,185	103,213	89,972
Sorghum	1,000 bu	10,409		10,409
Other	1,000 ton	44.9		44.9
Alcohol production:				
Fuel	1,000 gal	548,684	275,900	272,784
Industrial	1,000 gal	1,000	1,000	
Total	1,000 gal	549,684	276,900	272,784
Ethanol yield	Gal/bu	2.6623	2.6828	2.649
Feedstock costs	Dol./gal	0.8030	0.7965	0.8095
Byproducts credits:				
Distiller's dried grains	Dol./gal	0.2520	0.2433	0.2610
Carbon dioxide	Dol./gal	0.0060	0.0038	0.0080
Net feedstock costs	Dol./gal	0.5450	0.5494	0.5405
Cash operating expenses:				
Electricity	Dol./gal	0.0374	0.0400	0.0349
Fuels	Dol./gal	0.1355	0.1607	0.1099
Waste management	Dol./gal	0.0059	0.0077	0.0041
Water	Dol./gal	0.0030	0.0044	0.0015
Enzymes	Dol./gal	0.0366	0.0377	0.0365
Yeast	Dol./gal	0.0043	0.0039	0.0046
Chemicals	Dol./gal	0.0229	0.0231	0.0228
Denaturant	Dol./gal	0.0348	0.0356	0.0339
Maintenance	Dol./gal	0.0396	0.0319	0.0474
Labor	Dol./gal	0.0544	0.0609	0.0478
Administrative costs	Dol./gal	0.0341	0.0357	0.0325
Other	Dol./gal	0.0039	0.0035	0.0043
Total	Dol./gal	0.4124	0.4451	0.3802
Total cash costs and net feedstock costs	Dol./gal	0.9574	0.9945	0.9207

Feedstock Costs. Gross feedstock costs, the expenditures for purchase of corn, sorghum, and other grains, were 80.3 cents per gallon of ethanol produced (table 1). According to the survey, small ethanol plants purchased only corn, but large ethanol plants purchased corn, sorghum, and other feedstocks. The average feedstock cost was 79.7 cents per gallon for small plants and 81 cents for large plants.

Dry-mill ethanol plants produce many byproducts, including ethanol, carbon dioxide, wet distiller grains, modified distiller grains, distiller's dried grains, and condensed distiller soluble grains. Seventeen ethanol plants indicated that they sold wet and modified distiller grains in 2002. The average byproduct credit for all dry-mill ethanol plants was 25 cents per gallon. The byproduct credits for small and large ethanol plants were 24 cents and 26 cents per gallon, respectively. Only seven ethanol plants captured and sold carbon dioxide in 2002. The carbon dioxide credit for all dry-mill ethanol plants was less than 1 cent per gallon.

Net feedstock cost is the highest value input in the production of ethanol, ranging from 39 to 68 cents per gallon of ethanol in 2002 for the plants that participated in the survey (fig. 1).

Historical data for the net corn costs were estimated based upon USDA data and were derived from slightly different ethanol plant conversion factors than those found in this survey. Corn farm prices varied from $1.73 per bushel in 1987 to $3.92 per bushel in 1996. The price of corn byproducts is related to the price of soybean meal. The net corn cost for dry-mill ethanol plants ranged from 28 cents per gallon of ethanol in 1987 to $1.01 in 1996 (table 2). Corn and corn oil prices increased significantly in 2002 and 2003.

Cash Operating Expenses. Variable operating expenses include electricity, fuels, waste management, water, enzymes, yeast, chemicals, denaturant, maintenance, labor, administrative costs, and other. Fuel includes expenses for natural gas and purchased steam.

Figure 1

Net corn cost for ethanol plants, 2002

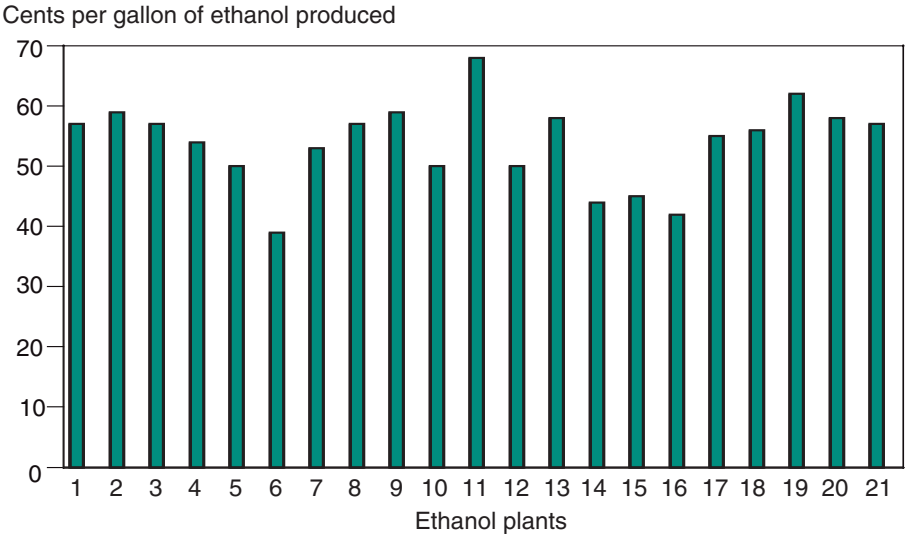


Table 2
Net corn costs per gallon of ethanol for dry and wet ethanol plants

Year	Corn	Corn gluten feed	Corn gluten meal	Distiller's dried grains	Corn oil	Dry mill net corn cost	Wet mill net corn cost
	$/bu	*$/ton*	*$/ton*	*$/ton*	*Cents/lb*	*$/gallon*	*$/gallon*
1984	3.20	94.88	244.58	150.00	29.81	0.75	0.72
1985	2.71	74.42	204.88	91.53	26.28	0.76	0.62
1986	2.10	94.33	216.16	115.29	18.49	0.44	0.37
1987	1.73	97.58	250.83	119.72	21.54	0.28	0.18
1988	2.41	123.00	308.75	145.28	23.56	0.46	0.34
1989	2.54	112.96	278.54	142.90	21.02	0.52	0.45
1990	2.54	92.67	234.58	138.26	25.37	0.52	0.49
1991	2.52	99.83	248.75	133.65	28.39	0.53	0.43
1992	2.38	102.55	263.08	123.27	23.99	0.51	0.39
1993	2.42	85.76	294.30	115.92	21.77	0.55	0.45
1994	2.54	89.56	262.67	120.82	27.34	0.58	0.47
1995	2.81	87.45	241.34	107.49	26.58	0.73	0.59
1996	3.92	115.85	332.08	151.92	24.52	1.01	0.93
1997	2.71	84.13	345.84	126.36	24.95	0.63	0.52
1998	2.30	65.20	258.83	85.86	29.87	0.59	0.41
1999	1.95	58.94	231.75	82.56	23.36	0.47	0.35
2000	1.96	51.51	240.21	75.62	14.96	0.50	0.42
2001	1.95	62.16	254.77	91.84	15.65	0.44	0.38
2002	2.23	60.27	245.03	83.76	20.57	0.57	0.46
2003	2.44	63.92	245.26	90.84	28.49	0.63	0.49

Electricity and fuels are the largest cost components of operating expenses. The average energy expenditure for all dry-mill ethanol plants was 17.29 cents per gallon of ethanol produced in 2002. Energy cost per gallon of ethanol was more than 5 cents per gallon higher for small ethanol plants than for large ethanol plants. Large plants are more energy efficient than small plants.

Energy cost per gallon of ethanol for dry-mill ethanol plants in 2002 was higher than in 1998. Natural gas prices increased significantly, from $2.08 per MMBTU (million British thermal units) in 1998 to $3.36 in 2002. The price of natural gas in 2002 was 61 percent higher than in 1998.

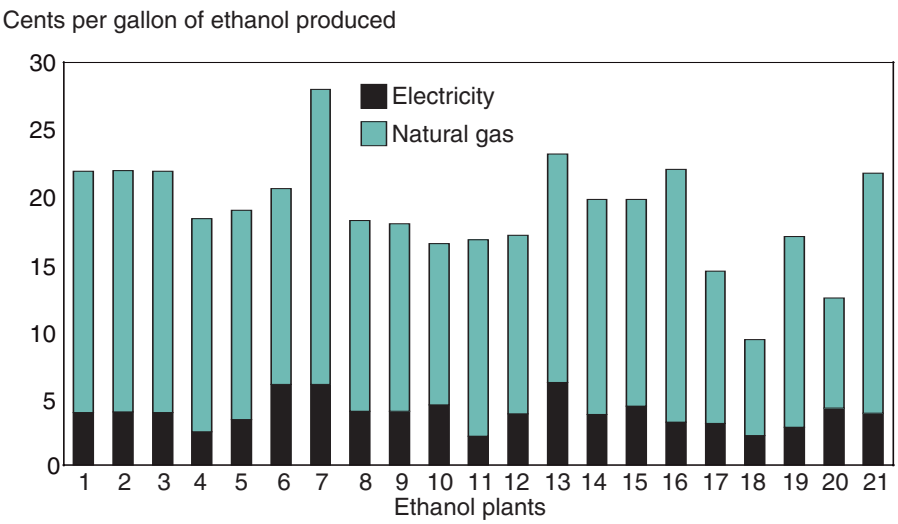
Variable cost components varied widely across the plants in the survey. For instance, electricity ranged from 2 to 6 cents per gallon of ethanol produced, and natural gas ranged from 8 to 22 cents per gallon. Total energy used by ethanol plants varied from 11 to 28 cents per gallon in 2002 (fig. 2). Labor costs ranged from 3 to 11 cents per gallon and maintenance costs from 1 to 7 cents per gallon.

Some cost components showed less variation across the ethanol plants of different sizes surveyed in 2003. Enzymes, yeast, denaturant, and chemicals were nearly constant at 4, 1, 4, and 2 cents per gallon, respectively. Larger plants generally incurred lower expenses per gallon of ethanol for labor and maintenance.

Management, administration, insurance, and tax expenses ranged from 1 to 18 cents per gallon. Some of these differences may be attributed to differences in accounting for management and personnel, with small plants allocating more of the payroll to management overhead.

Figure 2

Electricity and natural gas used in ethanol production, 2002



Comparison of Ethanol Production Costs, 1998 and 2002

The last ethanol production cost survey by USDA described the industry in 1998. Table 3 provides 1998 and 2002 survey data. The 1998 survey covered both dry-and wet-mill ethanol plants, while the 2002 survey covered only the dry-mill ethanol plants. The sample sizes and total ethanol production capacity for both surveys were large enough to provide reliable estimates of industry averages.

The results of the surveys indicate that total operating costs in 2002 did not change from 1998. Total cash operating costs were $0.42 per gallon in 1998 and $0.41 per gallon in 2002. Fuel costs in 2002 were 50 percent higher than in 1998 due to higher natural gas prices. In contrast, labor and enzyme costs were 26 and 35 percent lower, respectively, in 2002 than in 1998. Lower expenses for enzymes and labor offset the higher expenses for fuels. Lower labor expenses were due to new ethanol plants being more labor efficient than older ones. Lower enzyme expenses were due to declining costs and a smaller volume of enzymes used per gallon of ethanol.

Plant Capacity and Cost

The 21 ethanol plants in the survey had a total annual production capacity of 670 million gallons per year in 2002. Plant capacity ranged from 9 million gallons per year to more than 90 million gallons per year; the weighted average capacity was 32 million gallons per ethanol plant per year.

Ownership of the surveyed plants was highly diversified. Five ethanol plants were farmer-owned cooperatives and four were limited-liability companies. In addition, three plants were investor owned and one was owned jointly by a farmer-owned cooperative and an investor-owned partnership. In addition, four ethanol plants were privately owned, two were limited partnerships, and one was owned by a farmer-owned cooperative and a limited partnership.

Table 3
Ethanol cost of production, dry milling process, 1998 and 2002

	U.S. average 2002	U.S. average 1998
	$/gallon	*$/gallon*
Feedstock costs	0.8030	0.8151
Byproduct credits:		
Distiller's dried grains	0.2520	0.2806
Carbon dioxide	0.0060	
Net feedstock costs	0.5450	0.5345
Cash operating expenses:		
Electricity	0.0374	0.0409
Fuels	0.1355	0.0901
Waste management	0.0059	0.0056
Water	0.0030	0.0025
Enzymes	0.0366	0.0559
Yeast	0.0043	0.0068
Chemicals	0.0229	0.0270
Denaturant	0.0348	0.0230
Maintenance	0.0396	0.0359
Labor	0.0544	0.0732
Administrative costs	0.0341	0.0366
Other	0.0039	0.0196
Total	0.4124	0.4171
Total cash costs and net feedstock costs	0.9574	0.9516

New Construction. Total ethanol production capacity by the 21 plants at the startup was 418 million gallons per year. Average capital invested per gallon at the startup date was $1.57 per gallon. Construction costs for individual plants ranged from $1.05 to $3.00 per gallon in 2002 (fig. 3). The average capital cost of building new ethanol plants is lower than in the past, possibly due to larger plant designs that more fully exploit economies of scale. A detailed analysis of the relation between construction costs and plant size is given in Gallagher, Brubaker, and Shapouri (2005).

Expansion. Of the 21 ethanol plants responding to the survey, 16 increased their capacity in 2002 by a combined 253 million gallons per year (fig. 4). As a result, total ethanol production expanded from 418 million gallons at startup to 670 million gallons in 2002. Nine of the 21 plants indicated they planned to expand their production by 2004/05.

Average capital invested to expand the existing ethanol production capacity was $0.50 per gallon and ranged from $0.20 to $1.00 per gallon (fig. 3). Hence, expansion, when it is feasible, tends to cost less than new capacity.

Bioenergy Program. Twenty of the 21 surveyed plants participated in the USDA Commodity Credit Corporation (CCC) Bioenergy Program (see box). Ten ethanol plants used the existing excess capacities in 2002 to receive the incentive from USDA. Ten ethanol plants were new or had added new production capacity in 2002 to qualify for the CCC Bioenergy Program.

Figure 3

Capital investment in ethanol plants

Dollars per gallon of ethanol

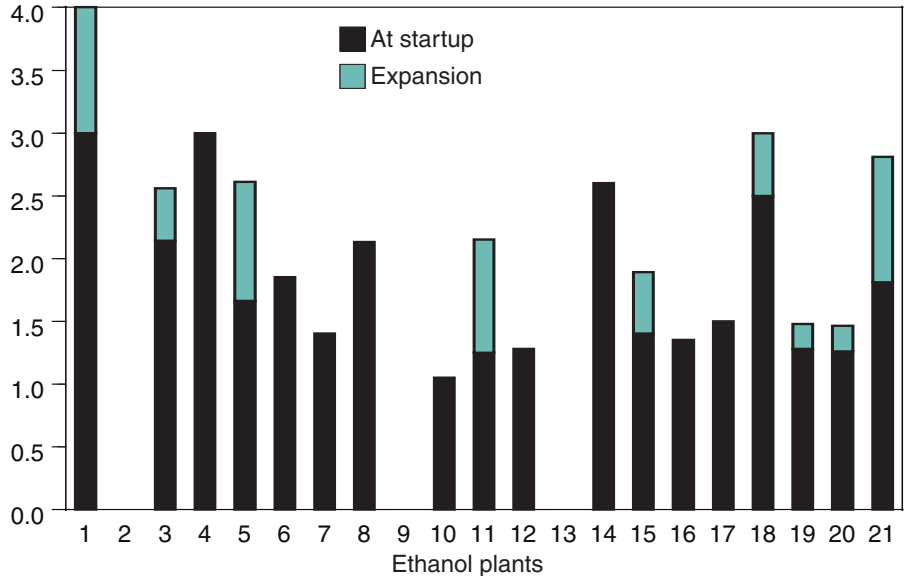
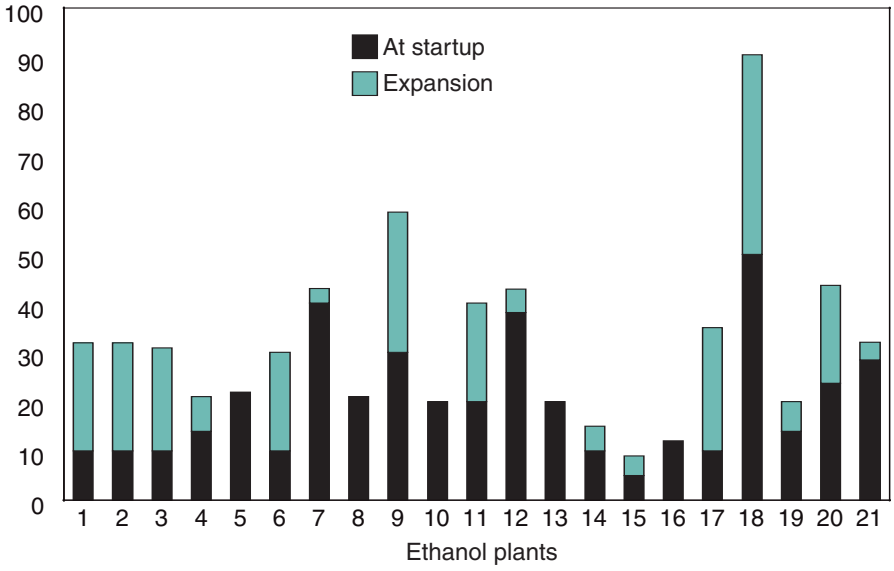


Figure 4

Production capacity of ethanol plants at startup and in 2002

Million gallons of ethanol



Commodity Credit Corporation Bioenergy Program

USDA's Bioenergy Program reimburses to U.S. commercial bioenergy (fuel grade ethanol and biodiesel) producers some of their input costs for commodities (corn, soybean, sorghum, wheat, etc.) used to increase their bioenergy production. Payment is based on production that is an increase from the previous fiscal year. For FY 2005, the program also pays biodiesel producers for base production (production that is not an increase from the previous fiscal year) at 15 percent of the rate of increased production. A prorata factor is also applied when requested payments exceed the annual available funding.

Payments are issued at the end of each quarter based on local commodity prices. Producers with total annual production of:

- less than 65 million gallons are reimbursed the cost of 1 feedstock unit for every 2.5 units used for increased production, and
- 65 million gallons or more are reimbursed the cost of 1 feedstock unit for every 3.5 units used for increased production.

The program has supported growth in the bioenergy industry by making payments of:

- $40.7 million on 147.7 million gallons of production in FY 2001, for an average of $0.276 per gallon,
- $78.7 million on 228.1 million gallons of production in FY 2002, for an average of $0.345 per gallon,
- $150.0 million on 626.5 million gallons of production in FY 2003, for an average of $0.234 per gallon (payments were capped by the available funding),
- $150.0 million on 621.7 million gallons of production in FY 2004, for an average of $0.241 per gallon (payments were capped by the available funding),
- $43.7 million to date in FY 2005 on 301.0 million gallons of bioenergy production.

The program ends, under its current authority, at the end of FY 2006. The program has funding of $100 million for FY 2005. Program provisions also provide for a payment limitation per producer of 5 percent of available funds per fiscal year. Thus, a payment limitation of $5 million is in effect for FY 2005 payments.[1]

[1]There are one-time payments associated with the new production capacity.

For more information, contact James Goff at (202) 720-5396 or by e-mail at James.Goff@usda.gov.

Input Requirements and Productivity

Ethanol processors have improved their cost performance because new technology enables processors to obtain more output with the same inputs and to produce the same output using less inputs. We report the results of survey respondents' standard physical performance measures in ethanol processing.

Feedstock Use and Ethanol Yield

Corn was the main feedstock for production of ethanol in 2002 for the ethanol plants surveyed. Only 1 of 21 ethanol plants used a mixture of feedstocks such as of corn, sorghum, and wheat starch for production of ethanol (fig. 5).

Ethanol yield per bushel of corn varied among the ethanol plants. Ethanol yield per bushel of corn was directly related to the amount of fermentable starch in the corn kernels, the plant's efficiency, the plant's age, types of equipment, and plant management. In addition, new ethanol plants have very high ethanol yield per bushel of corn. For the ethanol plants surveyed, ethanol yields in 2002 ranged from 2.5 to 2.8 gallons per bushel, with a weighted average of 2.68 gallons per bushel (fig. 6).

Energy Use in Ethanol Plants

Dry-mill ethanol plants use electrical and thermal energy. Electrical energy is used in motors and pumps, while thermal energy, in the form of steam and hot air, is used in liquefaction, fermentation, distillations, and drying byproducts. On average, the ethanol plants surveyed used 1.19 kilowatt hours (kWh) of electricity per gallon of ethanol in 2002. Individual ethanol plant electricity use ranged from 0.6 to more than 2.0 kWh per gallon of ethanol (fig. 7).

Figure 5
Types of feedstock used in production of ethanol, 2002

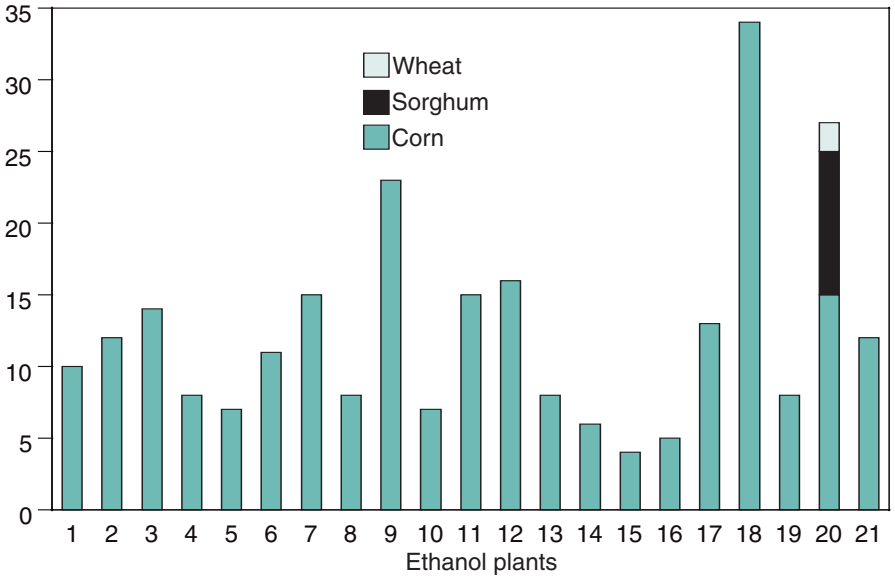


Figure 6
Ethanol yield per bushel of corn and ethanol production, 2002

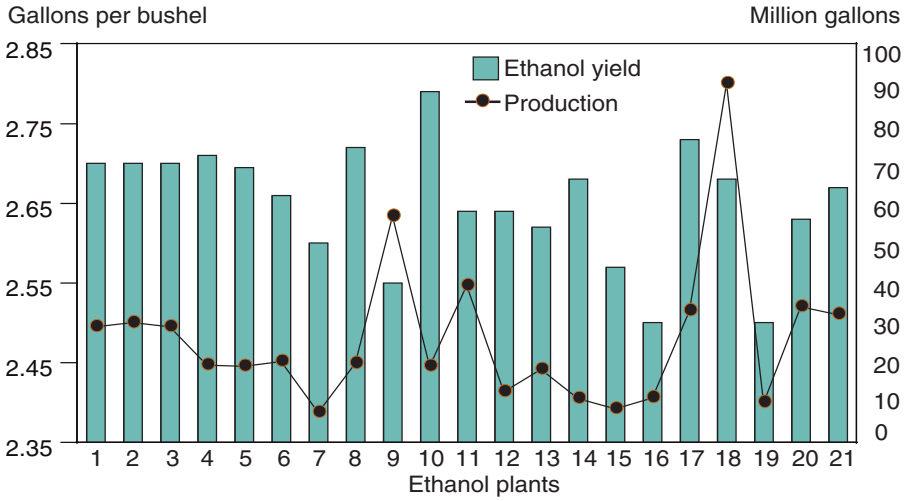
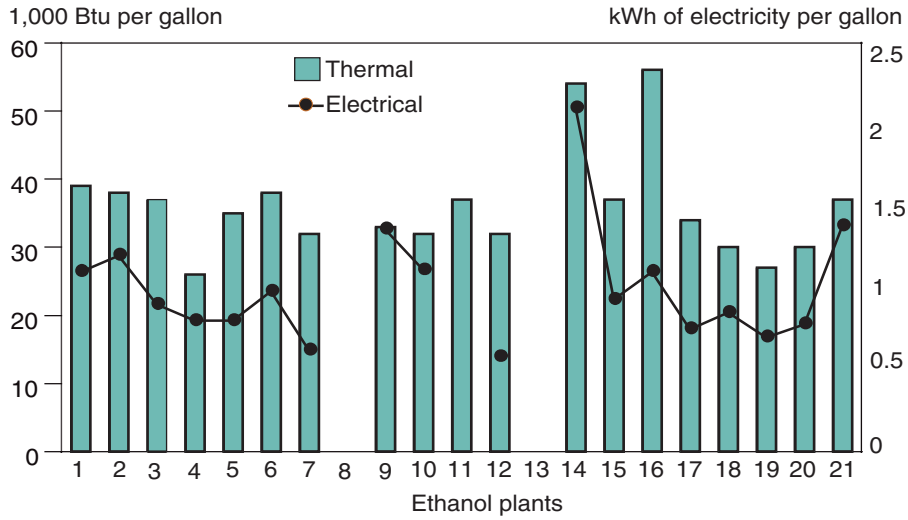


Figure 7
Thermal and electrical energy used in production of ethanol, 2002



Ethanol plants use natural gas to produce steam to convert corn to ethanol. On average, the surveyed ethanol plants used 34,800 Btu of thermal energy per gallon of ethanol. Thermal energy used per gallon of ethanol varied among ethanol plants and ranged from 26,000 to 54,000 Btu per gallon in 2002 (fig. 7).

Due to high prices of natural gas, some ethanol plants recently reduced their energy consumption by partially removing the moisture from distiller's grains. Production of wet distiller's grains (WDG) and modified distiller's grains (MDG) instead of distiller's dried grains (DDG) lowers the plant's energy requirements.

Also, each ethanol plant has a yearly allowance of volatile organic compound (VOC) emissions according to Environmental Protection Agency (EPA) standards. VOC emissions are directly related to the drying of distiller's grains. Since some larger dry mills are near the VOC limit, a plant's shift to MDG or WDG may also be aimed at reducing emissions, especially when there is a local market for the livestock feed.

Alternatively, large dry mills in cash grain areas may continue DDG production and participate in the byproduct export market. In this circumstance, the processor may use a thermal oxidizer to reduce VOC emissions. Then natural gas use will remain high because the oxidizer uses natural gas input.

Both approaches, wet byproducts and oxidization, permit larger scale plants that stay below VOC emission limits. Hence, larger plants and further exploitation of scale economies may be an avenue for offsetting increasing energy prices.

Labor Use in Ethanol Plants

Total labor use in the ethanol plants is directly related to the size and age of the plant. New ethanol plants are more labor efficient through using automation technology, which greatly reduces labor requirements. Large plants have more employees than small plants, but labor use per million gallons of ethanol is inversely related to the size of the plant (economy of size). Plant labor in this survey includes the general manager, plant manager, purchasing manager, laboratory manager and technicians, shift supervisors, plant operators, maintenance supervisor, craftsmen, laborers, instrument technicians, and others. For the surveyed ethanol plants, the total number of employees averaged 34 persons per plant and ranged from 20 to 135 (fig. 8).

Percent of Ethanol in the Beer

The percentage of ethanol in the beer varied by plant and is directly related to the type of yeast used in fermentation, the age of the plant, and the plant's operating efficiency.[2] Alcohol concentration in the beer is higher for the new variety of yeast and yeast with more tolerance to higher temperatures. Plants that responded to the survey question about alcohol yields said that they ranged from 12 to 18 percent. The weighted average alcohol in the beer for all ethanol plants was slightly over 15 percent in 2002 (fig. 9).

[2]"Beer" is the raw product of processing before ethanol is distilled/extracted.

Figure 8

Labor used in ethanol production

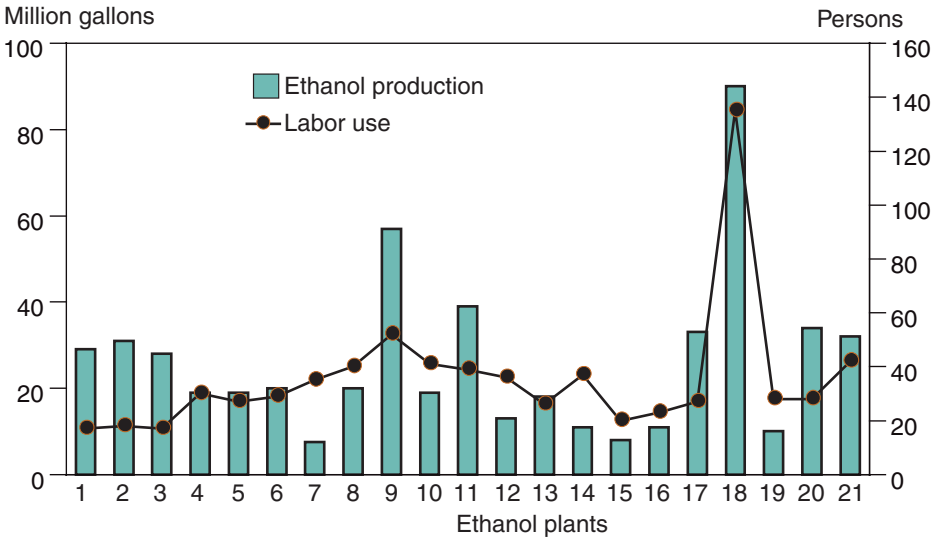
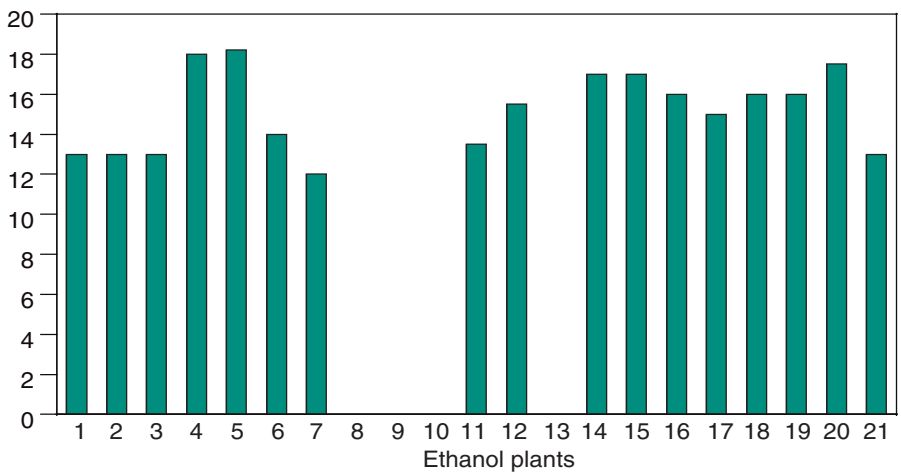


Figure 9

Percent of alcohol in the beer, 2002



Water Use

Water is essential in producing ethanol, particularly in the grinding, liquefaction, and fermentation processes. The amount of water used per gallon of ethanol has declined significantly in recent years. Old ethanol plants used more than 15 gallons of water per gallon of ethanol; among the plants surveyed in 2002, water use ranged from less than 1 gallon to 11 gallons per gallon of ethanol and averaged 4.7 gallons per gallon of ethanol (fig. 10).

Ethanol plants require processed water to produce ethanol. Water discharged from plants (wastewater) contains organic compounds that cannot be discharged into rivers. The wastewater discharge must be treated in the ethanol plant or connected to local wastewater treatment facilities. New ethanol plants have zero discharge of wastewater and do not need to connect to the local wastewater treatment service, thus allowing for plants to locate in more rural locations closer to the sources of raw materials. To decrease wastewater in the ethanol plants, anaerobic digesters are used to degrade the organic compounds. This process produces methane gas, which can be used as an alternative energy source for the DDG dryer. Anaerobic digesters remove 85 to 95 percent of organic compounds. The removal of these compounds can eliminate the need for traditional waste treatment, which can often save $500,000 to $1 million in capital investment costs.

Fermentation

Two types of fermentation are used in the ethanol industry, continuous and batch. Based on the 2002 survey of ethanol plants, 27 percent of ethanol was produced through continuous fermentation and 73 percent was produced using the batch process. The continuous fermentation system is very common among large ethanol plants. The continuous fermentation system was used in 4 ethanol plants, and the batch fermentation system was used in 17 ethanol plants.

Fermentation times varied among ethanol plants. The average fermentation time for all plants surveyed was 52.3 hours, ranging from 46 to 72 hours. Fermentation times are longer in the continuous fermentation process than in the batch fermentation process (fig. 11).

Figure 10

Gallons of water used per gallon of ethanol, 2002

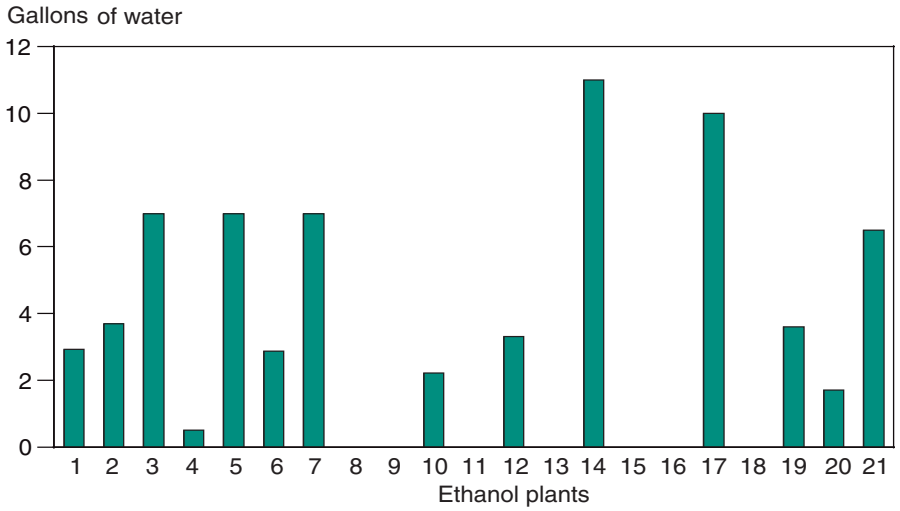
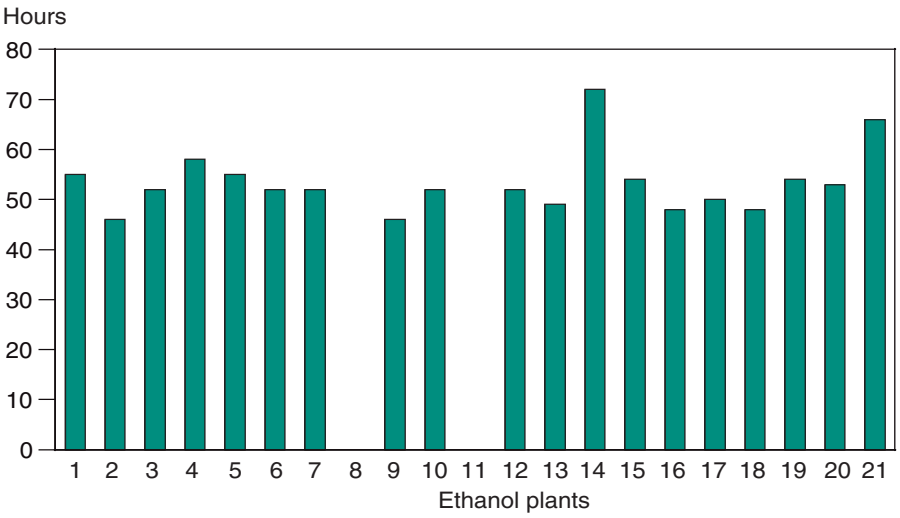


Figure 11

Fermentation time, 2002



Marketing

As the industry has expanded, marketing has grown from a purely local operation to a national and international enterprise. This section reports the form of product sales, the mode of transport, and the destination of the product.

Types of Ethanol Products and Methods of Sale

All ethanol plants that participated in the survey produced fuel grade ethanol (anhydrous). Only one ethanol plant produced a very small amount (1 million gallons) of industrial ethanol. In 2002, 99 percent of total ethanol was sold in the domestic market, and the rest was exported. Thirty percent of total ethanol produced by the surveyed plants sold by cash, and 70 percent sold by contract.

In 2002, 20 percent of ethanol was sold to terminal storage, 25 percent directly to blenders, and 55 percent to marketers (fig. 12). Ethanol produced by the surveyed ethanol plants was distributed in Chicago and Milwaukee, the West Coast, Minnesota, and other States. Forty-seven percent of the total ethanol produced by the 21 ethanol plants was sold in the Chicago-Milwaukee market; 28 percent in California, Arizona, Nevada, and Washington; 17 percent in Minnesota; and the rest in Colorado, Missouri, Michigan, Kansas, Nebraska, and North Dakota. A small volume of ethanol was exported to Canada in 2002 (fig. 13).

Mode of Transportation for Ethanol and Byproducts

Trucks and railroads were used to transport ethanol from plants to terminal storage, blenders, and ethanol marketers. Forty-six percent of total ethanol produced by the surveyed ethanol plants in 2002 was shipped from the plants by trucks, and 54 percent was shipped by rail. Trucks were usually used for short distances (average of 93 miles), while railroads were used for

Figure 12
Ethanol buyers, 2002

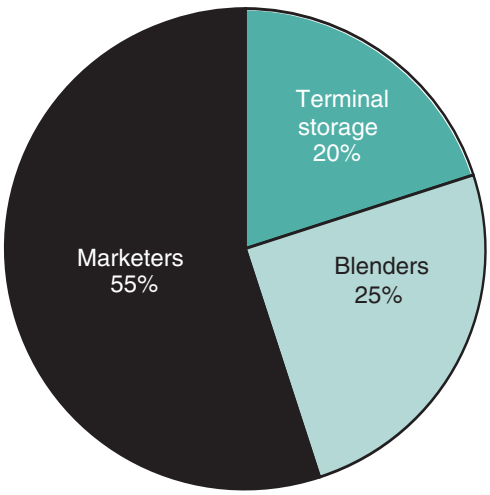
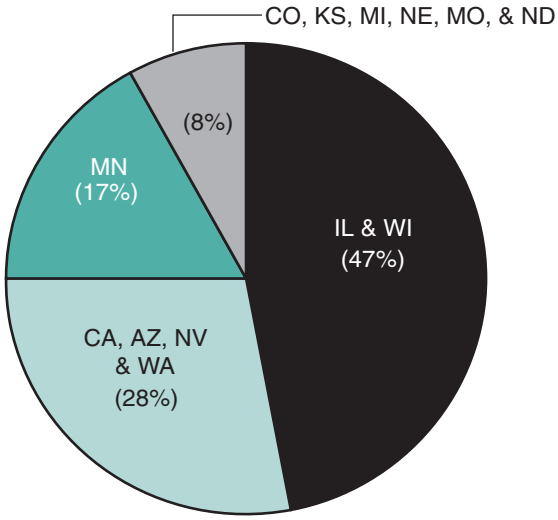


Figure 13
Geographic distribution of ethanol production, 2002



longer hauls. The average distance that ethanol was shipped by rail was 1,163 miles. One-way distances to ship ethanol by truck ranged from 30 to 250 miles. One-way distances to ship ethanol by rail to blenders or terminal storage ranged from 800 to 2,500 miles.

In 2002, the surveyed ethanol plants sold about 1 million tons of wet distiller's grains (WDG) with 35 percent solid, about 330,000 tons of modified distiller's grains (MDG) with 50 percent solid, and 1.26 million tons of distiller's dried grains (DDG) with 90 percent solid. In 2002, the plants converted all distiller's grains to dry basis (100 percent solid)—21 percent of total DDG was sold as WDG, 9 percent as MDG, and 70 percent sold as DDG (fig. 14). In addition, surveyed ethanol plants sold 125,000 tons of condensed distiller's soluble grains and 335,000 tons of carbon dioxide.

Trucks were used to transport WDG and MDG. In 2002, 16 ethanol plants sold WDG. The WDG and MDG contain 65 and 50 percent moisture, respectively, and have a very short shelf life—3 to 4 days. The shelf life could be extended to 4 weeks with the help of distiller's grains preservatives. Due to the short shelf life and high moisture content, the wet distiller's grains must be used near the ethanol plants. Buyers for WDG averaged 50 miles from the ethanol plant, ranging from 25 to 200 miles.

Trucks, trains, and barges were used to transport DDG. Trucks and barges were used for short distances, while railroads were used for long hauls. For the surveyed plants, the average distance for trucks was 161 miles, for barges 200 miles, and for railroads 994 miles (fig. 15). One-way distance for shipping by truck ranged from 50 to 600 miles and by rail ranged from 200 to 3,000 miles.

DDG production per gallon of ethanol varied among the ethanol plants. In 2002, on average, 6.7 pounds DDG (10 percent moisture) were produced per gallon of ethanol, ranging from 5.6 to over 8 pounds per gallon (fig. 16).

Figure 14

Ethanol byproducts sale (dry basis), 2002

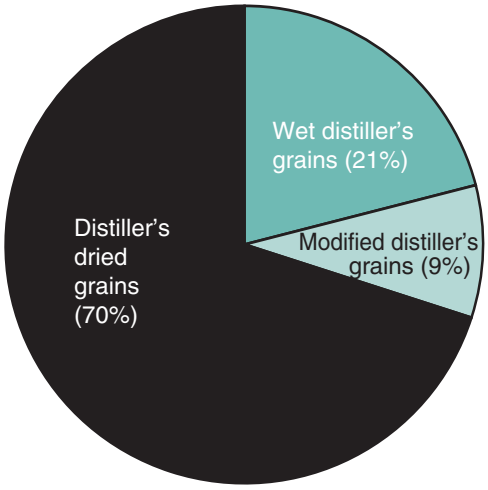


Figure 15

Modes of transportation and average distance hauled for distiller's dried grains, 2002

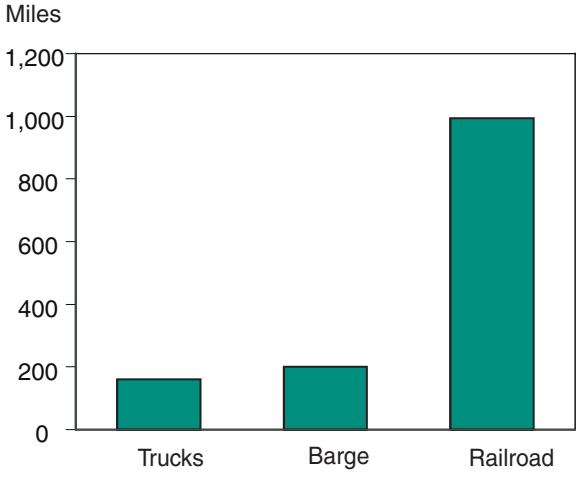
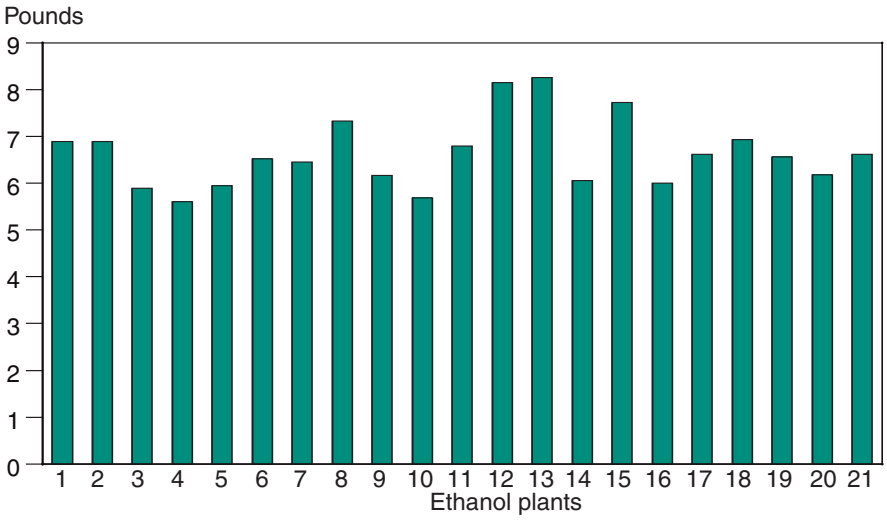


Figure 16

Pounds of distiller's dried grains (10% moisture) produced per gallon of ethanol, 2002



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