Economics of Germ Preseparation for Dry-Grind Ethanol Facilities

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ABSTRACT

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A detailed economic analysis of a 914 tonnes/day (36,000 bu/day) "Quick Germ" ethanol process was performed. The Quick Germ ethanol process is a combination of a dry-grind and a wet-milling ethanol process. The Quick Germ ethanol process increases the coproduct value in the dry-grind ethanol process by recovering germ before fermentation. Germ is recovered using the conventional wet-milling degermination process. Economic assessment of the Quick Germ process proved profitable. The savings achieved by recovering germ as a coproduct and by increasing the fermentor capacity due to removal of nonfermentables from the corn mash will reduce the manufacturing cost of ethanol by 2.69 ¢/L (10.19 ¢/gal or $0.265/bu) when compared to the conventional dry-grind ethanol process.

Ethanol production from corn has benefited from various technological innovations that have reduced processing costs. The costs of ethanol production can be categorized as feedstock (the difference between the cost of corn and the total revenue received from the sale of coproducts), capital, and operating costs (Rendleman and Hohmann 1993).

Ethanol is produced from corn mainly by two processes: 1) wet-milling (Fig. 1) and 2) dry-grind (Fig. 2). The dry-grind process is commonly known as dry-milling in the ethanol industry (Maisch 1987). Dry-grind is the preferred terminology for the ethanol process in which dry whole corn is hammer-milled to achieve size reduction before cooking, saccharification, and fermentation (Eckhoff and Paulsen 1995). Dry-milling should be used to refer to a very specific separation technique, where corn is milled and separated into products for use in the food processing and snack food industries (Eckhoff and Paulsen 1995).

Singh and Eckhoff (1996) proposed changes to the dry-grind process (Fig. 3) by recovering the germ from the wet-milling degermination before grinding the remaining material. This process, called the "Quick Germ" process, is expected to lower feedstock costs in ethanol production by increasing the value of coproducts recovered in the dry-grind ethanol process. The Quick Germ process involves soaking whole corn in water for 3–12 hr at ≈60°C before conventional wet-milling degermination and germ recovery. Soaking of whole kernels results in differential swelling of corn components which loosens the attachment of the various grain components to one another. After soaking the corn, a conventional Bauer mill is used for degermination, as is used in wet-milling. The germ is recovered by using germ hydrocyclones (Blanchard 1992), and the rest of the corn is ground wet and then processed by normal dry-grind alcohol methods. The corn oil and the germ meal recovered from the germ has a much higher value of $0.53–0.66/kg ($0.24–0.30/lb) as a coproduct than the $0.13–0.20/kg ($0.06–0.09/lb) from the Distiller Dried Grains (DDG). There is also a cost savings associated with increased fermentor capacity due to removal of nonfermentables from the corn mash (Singh 1995, Singh and Eckhoff 1995).

The purpose of the present work was to perform an engineering-economic assessment of ethanol production by the Quick Germ ethanol process. A comparison was done between the Quick Germ ethanol process and a conventional dry-grind ethanol process.

Economic Evaluation

Economic model. Liegois (1996) developed an economic model for the dry-grind ethanol process used for this study. This model is based on a capacity of 914 tonnes/day (36,000 bushels/day) and produces 354,315 L of fuel ethanol/day (93,600 gal/day), which corresponds to an annual production of 124,010,090 L (32,760,000 gal), based on 350 days of operation per year. A 124,010,090 L (32,760,000 gal) ethanol plant represents a medium-sized dry-grind ethanol plant in the United States.

Plant investment, operation assumptions, and economic analysis for the dry-grind ethanol process. Tables I–III summarize the plant investment, operating assumptions, and costs of raw materials and utilities for the dry-grind ethanol process. Table I lists the factors used to calculate the fixed capital investment from the total delivered equipment cost. These factors were calculated from the economic model developed by Liegois (1996). As shown, the fixed capital investment is 2.994 × the total equipment cost. Other assumptions concerning plant operation and the derivation of fixed production costs are given in Table II.

Table III provides the raw materials and utilities costs used for the dry-grind ethanol process. The cost of corn ($2.75/bu) and DDG were estimated based on historical averages (1993-1995), not current market prices. The value of germ was calculated based on its oil content, amount of germ meal, and processing cost of

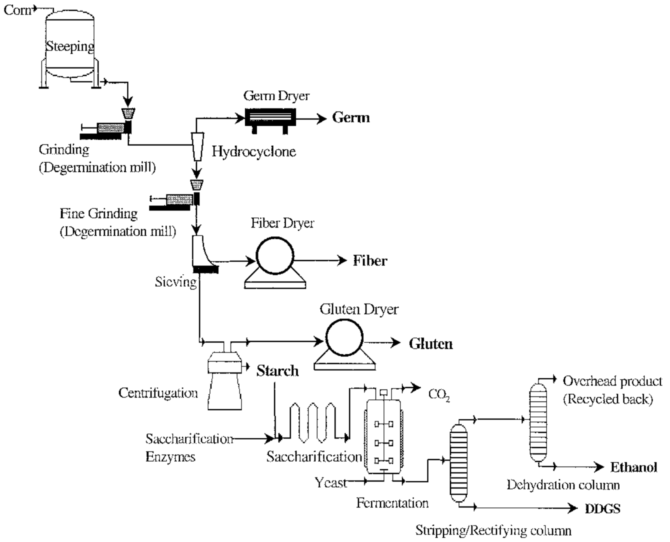

Fig. 1. Schematic diagram of the corn wet-milling process for ethanol production.

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germ. A germ oil content of 44.5%, obtained at the optimum soaking conditions of 12 hr and 59°C (Singh and Eckhoff 1996), was used to determine the germ value. The costs of utilities were based on Midwest installation. The natural gas represents the fuel cost used for producing steam and for direct drying.

Retrofit model for incorporating Quick Germ ethanol. Since Quick Germ ethanol technology involves changes in the front end of the dry-grind ethanol process, it is possible to retrofit a conventional dry-grind ethanol plant with the Quick Germ process at a substantial cost savings over a new plant. For the retrofitted plant, the additional capital investment is mainly for the degermination equipment. The multiplication factors used for calculating the total fixed capital for a retrofitted plant are different than those used for the dry-grind ethanol process (Table I). For a retrofitted plant, costs for some factors (site, steel, boiler) would not apply while others (concrete, buildings, electrical, piping, and instrumentation and control) would be greatly reduced (≈50%) because the existing plant would already contain most of the necessary equipment and supplies. Engineering and other costs would also not apply since these would be available within the existing plant. A factor of 0.6 for the retrofitted plant accounts for the increased ethanol evaporation and dehydration capacities and also for the additional carbon dioxide handling equipment.

Table IV gives the equipment capacities, number of units, and purchased equipment cost for degermination equipment and total fixed capital required to retrofit a dry-grind ethanol plant. The price information on degermination equipment was obtained from wet-milling equipment suppliers. Equipment was slightly oversized to take into account any fluctuations in daily grind rate. Fixed expenses, such as overhead, maintenance, insurance, and taxes, increase with increased retrofitted capital. Depreciation of the new equipment was straight line over 13.5 years, and the salvage value was assumed to be zero. Utility costs were calculated for the retrofitted plant.

A germ yield of 6.76%, obtained at the optimum soaking conditions of 12 hr and 59°C (Singh and Eckhoff 1996), was used to calculate the added revenue. Removal of germ at the front end of the process increases the fermentor capacity downstream by ≈7% and, therefore, the daily grind rate can be increased by ≈7%. This fact (i.e., increase in grind rate) was taken into account in the economic analysis of the retrofitted plant. The payback period for the retrofit capital investment was calculated from the added revenue generated by recovering germ as a coproduct and from the increased ethanol production due to the increase in daily grind. A comparison of the conventional dry-grind ethanol process and retrofitted Quick Germ ethanol process is given in Fig. 4.

Sensitivity analysis of soak time and soak temperature. Singh and Eckhoff (1996) determined the germ recovery and germ oil content for different combinations of soak time and temperature. A sensitivity analysis of the manufacturing price of ethanol was done for all combinations of soak time and temperature. Costs (equipment and processing) associated with these process variables (soak time and temperature) were changed for the sensitivity analysis.

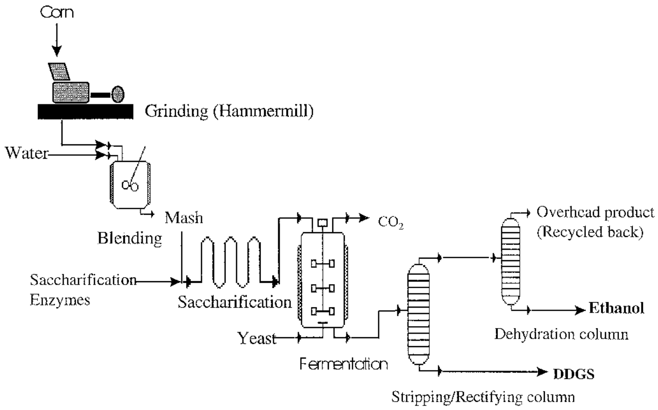


Fig. 2. Schematic diagram of the dry-grind process for ethanol production.

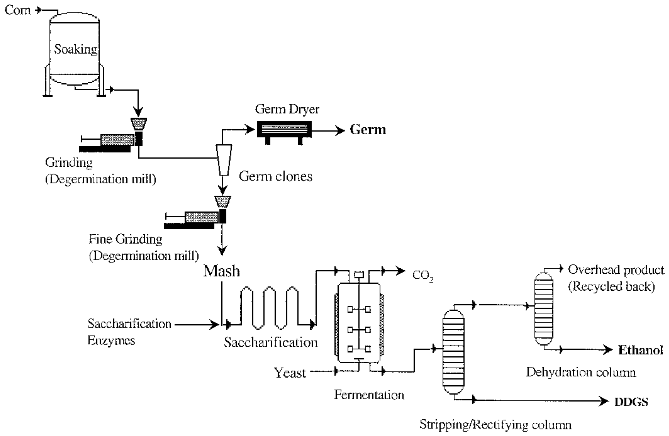
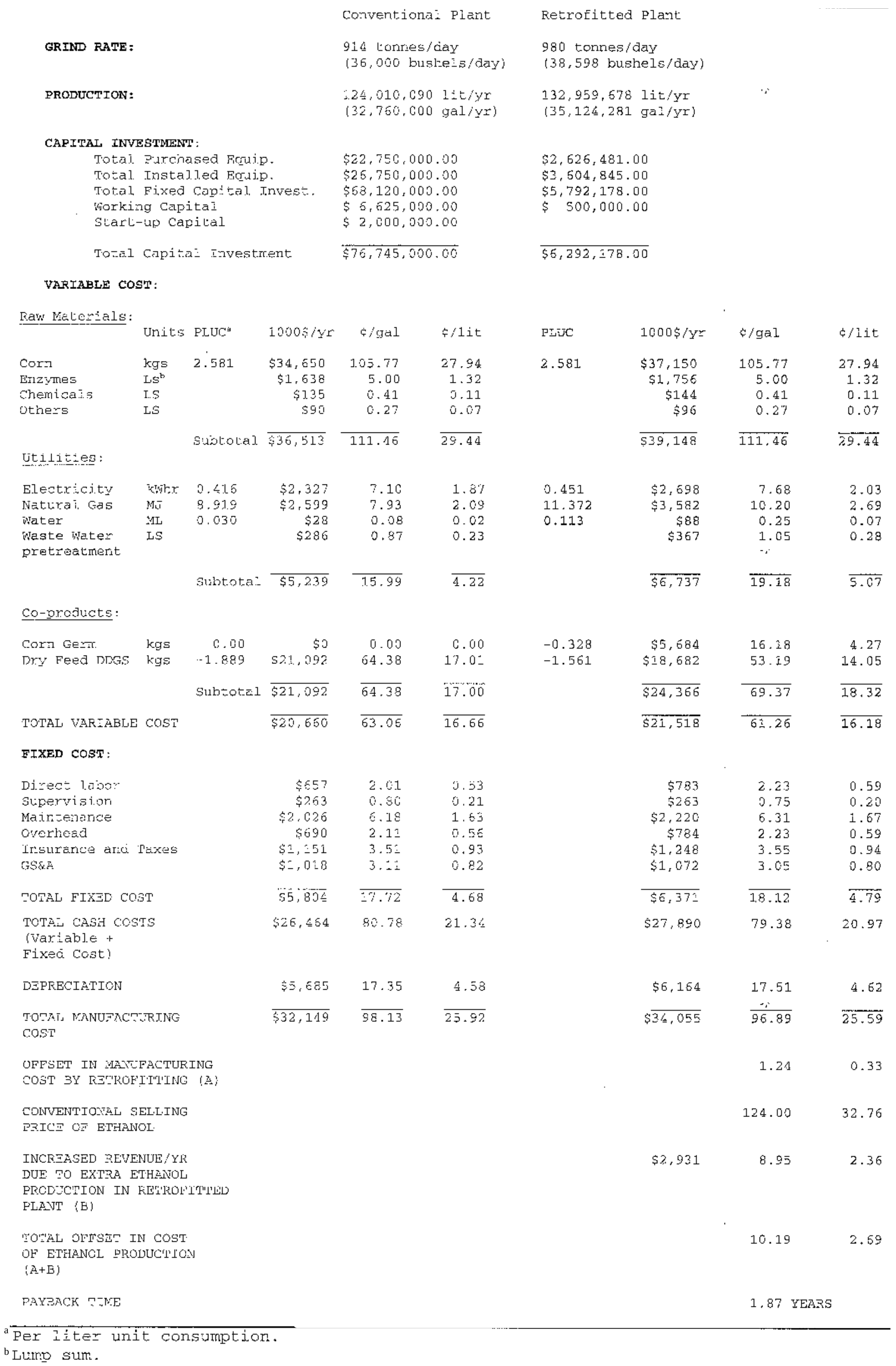


Fig. 3. Schematic diagram of the modified dry-grind ("Quick Germ") process for ethanol production.

TABLE I
Factors to Convert Equipment Costs to Fixed Capital Investment for the Dry-Grind Ethanol Process

	New Dry-Grind Facility	Retrofitted Dry-Grind Facility
Equipment Cost		
Site	0.0352	0.0000
Concrete	0.0219	0.0110
Steel	0.0352	0.0000
Buildings	0.0791	0.0396
Piping	0.1231	0.0616
Electrical	0.1011	0.0506
Instrumentation/control	0.1208	0.0604
Painting	0.0043	0.0022
Insulation	0.0152	0.0076
Boiler[a]	0.0219	0.0000
Increased ethanol dehydration and evaporation capacities and extra CO$_2$ handling equipment	0.0000	0.6000
Total installation cost	0.7450	0.3725
Total physical plant	2.3030	2.2053
Engineering, legal, and permits	0.4606	
Contingency	0.2303	
Total fixed capital	2.9940 × Equipment Cost	2.2053 × Equipment Cost

[a] Boiler efficiency was assumed to be 83%.



	Conventional Plant	Retrofitted Plant
GRIND RATE:	914 tonnes/day (36,000 bushels/day)	980 tonnes/day (38,598 bushels/day)
PRODUCTION:	124,010,090 lit/yr (32,760,000 gal/yr)	132,959,678 lit/yr (35,124,281 gal/yr)
CAPITAL INVESTMENT:		
Total Purchased Equip.	$22,750,000.00	$2,626,481.00
Total Installed Equip.	$26,750,000.00	$3,604,845.00
Total Fixed Capital Invest.	$68,120,000.00	$5,792,178.00
Working Capital	$ 6,625,000.00	$ 500,000.00
Start-up Capital	$ 2,000,000.00	
Total Capital Investment	$76,745,000.00	$6,292,178.00

VARIABLE COST:

Raw Materials:	Units	PLUC[a]	1000$/yr	¢/gal	¢/lit	PLUC	1000$/yr	¢/gal	¢/lit
Corn	kgs	2.581	$34,650	105.77	27.94	2.581	$37,150	105.77	27.94
Enzymes	LS[b]		$1,638	5.00	1.32		$1,756	5.00	1.32
Chemicals	LS		$135	0.41	0.11		$144	0.41	0.11
Others	LS		$90	0.27	0.07		$96	0.27	0.07
		Subtotal	$36,513	111.46	29.44		$39,148	111.46	29.44
Utilities:									
Electricity	kWhr	0.416	$2,327	7.10	1.87	0.451	$2,698	7.68	2.03
Natural Gas	MJ	8.919	$2,599	7.93	2.09	11.372	$3,582	10.20	2.69
Water	ML	0.030	$28	0.08	0.02	0.113	$88	0.25	0.07
Waste Water pretreatment	LS		$286	0.87	0.23		$367	1.05	0.28
		Subtotal	$5,239	15.99	4.22		$6,737	19.18	5.07
Co-products:									
Corn Germ	kgs	0.00	$0	0.00	0.00	-0.328	$5,684	16.18	4.27
Dry Feed DDGS	kgs	-1.889	$21,092	64.38	17.01	-1.561	$18,682	53.19	14.05
		Subtotal	$21,092	64.38	17.00		$24,366	69.37	18.32
TOTAL VARIABLE COST			$20,660	63.06	16.66		$21,518	61.26	16.18
FIXED COST:									
Direct labor			$657	2.01	0.53		$783	2.23	0.59
Supervision			$263	0.80	0.21		$263	0.75	0.20
Maintenance			$2,026	6.18	1.63		$2,220	6.31	1.67
Overhead			$690	2.11	0.56		$784	2.23	0.59
Insurance and Taxes			$1,151	3.51	0.93		$1,248	3.55	0.94
GS&A			$1,018	3.11	0.82		$1,072	3.05	0.80
TOTAL FIXED COST			$5,804	17.72	4.68		$6,371	18.12	4.79
TOTAL CASH COSTS (Variable + Fixed Cost)			$26,464	80.78	21.34		$27,890	79.38	20.97
DEPRECIATION			$5,685	17.35	4.58		$6,164	17.51	4.62
TOTAL MANUFACTURING COST			$32,149	98.13	25.92		$34,055	96.89	25.59
OFFSET IN MANUFACTURING COST BY RETROFITTING (A)								1.24	0.33
CONVENTIONAL SELLING PRICE OF ETHANOL								124.00	32.76
INCREASED REVENUE/YR DUE TO EXTRA ETHANOL PRODUCTION IN RETROFITTED PLANT (B)							$2,931	8.95	2.36
TOTAL OFFSET IN COST OF ETHANOL PRODUCTION (A+B)								10.19	2.69
PAYBACK TIME								1.87 YEARS	

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[a] Per liter unit consumption.

[b] Lump sum.

Fig. 4. Economic comparison of a conventional dry-grind ethanol plant and retrofitted plant using the "Quick Germ" ethanol process.

DISCUSSION

The comparison between the conventional dry-grind ethanol plant and the retrofitted plant (Fig. 4) shows that the retrofitted plant requires a total capital investment of $6,292,178. This total capital investment comprises of $5,792,178 for total fixed capital investment and $500,000 for the difference in the working capital between the retrofitted plant and the conventional plant. This extra capital investment reduces the manufacturing cost of ethanol by 2.69 ¢/L (10.19 ¢/gal or $0.265/bu). This corresponds to increased revenue of $3,578,104/yr compared to that of a conventional dry-grind ethanol plant.

The Quick Germ process increases the utilities cost by 0.85 ¢/L (3.19 ¢/gal or $0.083/bu) compared to that of a dry-grind ethanol process. This increased cost comes primarily from increased consumption of natural gas and electricity. Consumption of natural gas is increased due to the steam required for heating and then maintaining soak water at 59°C and for drying of germ. The increased electricity cost comes from the net increase in horsepower due to the installation of degermination equipment and the removal of hammermills. The water cost for the Quick Germ process increases almost three-fold. This increased water cost comes from the water required for soaking corn, flushing, and germ washing. Increased water consumption also increases the wastewater pretreatment cost.

The increase in the fixed cost for the Quick Germ process comes from increased direct labor cost, maintenance, overhead, and insurance and taxes. Degermination equipment will require one extra person per shift and will, therefore, increase the direct labor cost by 0.06 ¢/L (0.22 ¢/gal or $0.006/bu). Direct costs associated with maintenance, overhead, insurance and tax costs are fixed percentages of the total investment. Since the investment goes up in retrofitting the dry-grind ethanol plant to incorporate the Quick Germ process, these costs (maintenance, overhead, insurance and taxes) increase. Together these costs increase the cost of ethanol production in the retrofitted plant by 0.08 ¢/L (0.3 ¢/gal or $0.008/bu). Since general service and administration (GS&A) costs are 4% of other cash costs and other cash costs are lower in a retrofitted plant, the fixed cost associated with GS&A decreases by 0.02 ¢/L (0.06 ¢/gal or $0.001/bu) in a retrofitted plant (Fig. 4).

Recovered germ in a retrofitted plant contributes 4.27 ¢/L (16.18 ¢/gal or $0.420/bu) to the coproduct value and, therefore, reduces the total variable cost in a retrofitted plant by 0.48 ¢/L (1.8 ¢/gal or 0.047/bu). Increasing ethanol production by 8,949,777 L/yr (2,364,281 gal/yr) contributes 2.36 ¢/L (8.95 ¢/gal or 0.233/bu). Together, germ recovery and increased ethanol production reduce the manufacturing cost of ethanol by 2.69 ¢/L (10.19 ¢/gal or $0.265/bu).

TABLE II
Plant Investment and Operation Assumptions for the Dry-Grind Ethanol Process

Factor	Investment
Direct labor	$15 per hour average
Supervision	$20 per hour average
Maintenance	3% ISBL (inside battery limits) + 2% OSBL (outside battery limits)
Overhead	75% direct labor + supervision
Insurance/taxes	1.5% investment
General services	4% other cash costs
Depreciation	Straight line
Plant life	13.5 years
Capital charges	15% total investment
Total working capital	Includes costs for: 30 days of corn required to inventory the plant, 30 days of finished product ethanol, and accounts receivable on the product
Plant capacity	914 tonnes/day (36,000 bu/day)
Production period	350 days

There are other costs that can also add to the economic value of the Quick Germ process. Removal of oil (germ) in the Quick Germ process will reduce the fouling of the beer still (unit operation before distillation). Lipids have been known to cause fouling of heat-transfer equipment (Lund and Sandu 1981). Reduced fouling will reduce the downtime of heat transfer equipment for maintenance, increase the plant capacity, and result in lower energy costs. The dollar value associated with reduced or no fouling will add to the economic value of the Quick Germ process.

There might be other costs associated with an increase in the daily grind rate of the retrofitted plant and higher sugar load on the fermentors, such as an increase in yeast nutrition requirements and cost associated with starter yeast. However, we assume that any modest price increase will be mitigated by the dollar value associated with reduced or no fouling of the heat-transfer equipment.

Sensitivity analysis of soak time and soak temperature. Fig. 5 shows the sensitivity of the ethanol manufacturing price to soak time and temperature. The manufacturing price of ethanol showed more sensitivity to temperature than to time. The lowest price of 23.23 ¢/L (87.94 ¢/gal or 2.288/bu) was obtained at a soak time-temperature combination of 12 hr and 59°C. Fig. 5 shows the lowest cost trough at 59°C. At 59°C, the ethanol manufacturing price increased by 0.47 ¢/L (1.79 ¢/gal or 0.046/bu) as soak time decreased from 12 to 3 hr.

Sensitivity analysis of DDG price. Removing germ at the front end of the dry-grind ethanol process reduces the fat content of DDG and might affect the nutritional quality of DDG. However, it is not clear how much the fat content or protein quality is affected. Removal of germ at the front end of the dry-grind ethanol process

TABLE III
Prices for Raw Materials and Utilities for the Dry-Grind Ethanol Process

Material	Cost ($)
Raw materials	
Corn	$108.26/tonne ($2.75/bu, No. 2 Grade)
Enzymes	$0.01–0.013/L ($0.04–0.05/gal)
Chemicals	Lump sum
Other	Lump sum
Utilities	
Electricity	$0.045 per kWhr
Natural gas	$2.50 per Mbtu
Water	$0.026 per M L ($0.100 per M gal)
Wastewater	Lump sum
Cogeneration	None
Coproducts	
Corn germ	$0.287/kg ($0.13/lb)
Dry feed/DDG	$180/tonne ($0.09/lb)

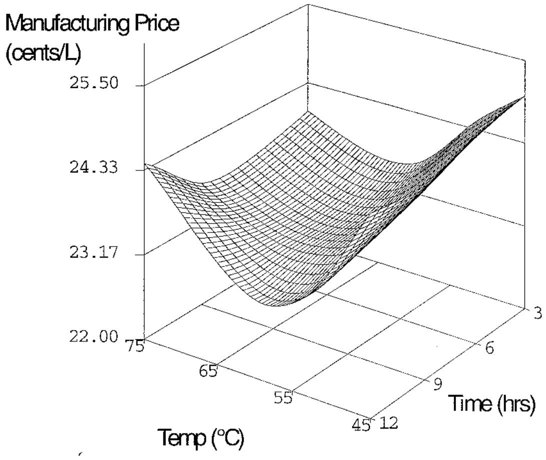

Fig. 5. Manufacturing price of ethanol at all levels of soak time and temperature.

TABLE IV
Equipment Costs for the Degermination Process in a Modified Dry-Grind Ethanol Plant

Equipment	Equipment Capacity/Unit (tonnes/day)	No. of Units	Purchase Cost
Soak tanks	330	3	$399,481
Equipment associated with soak tanks			$663,000
First grind screen	1016	1	$21,500
First grind mill with 150 H.P. motors	508	2	$118,000
Second grind screen	1016	1	$21,500
Second grind mill with 150 H.P. motors	508	2	$118,000
Germ clones (9" (4+3) LGS DorrClones)	1016	2	$120,000
Germ wash screens	355	3	$64,500
Third grind mill with 250 H.P. motors	508	2	$264,000
Germ press with 75 H.P. motors	1016	1	$255,500
Germ dryer	1016	1	$581,000
Total purchased equip. cost			$2,626,481
Total installed equip. cost			$3,604,845
Total fixed capital			2.2053 × Equip. Cost = $5,792,178

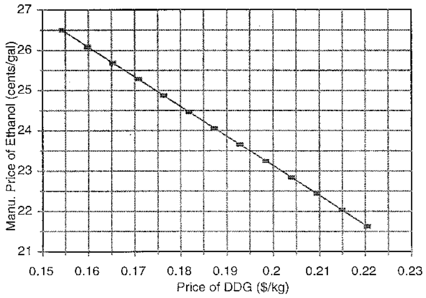

Fig. 6. Sensitivity of ethanol manufacturing price with respect to the Distiller Dried Grains (DDG) price.

might affect the DDG price on the downstream end, although the current DDG price is not based on fat content. The sensitivity analysis (Fig. 6) shows that the DDG price can be reduced by $0.033/kg ($0.015/lb) from its original price of $ 0.198/kg ($0.09/lb) and the Quick Germ process will still be economical compared to the conventional dry-grind process.

CONCLUSIONS

The Quick Germ ethanol process provides significant economic advantages for retrofitted dry-grind ethanol plants. It increases the revenue by recovering germ as a coproduct and by increasing the capacity of the plant. The payback time of the Quick Germ process is 1.87 yr making it a very profitable investment. The Quick Germ ethanol process reduces the manufacturing cost of ethanol by 2.69 ¢/L (10.19 ¢/gal or $0.265/bu) compared to that of the conventional dry-grind ethanol process. The DDG produced in the Quick Germ process will be lower in fat and protein content. However, it is not clear how much the fat content and protein quality will be affected. A detailed study on the nutritional characteristic of DDG from the Quick Germ process is warranted.

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